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FREEZING INJURY OF APPLES [1]

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INTRODUCTION

The growing and marketing of apples are foremost among fruit industries of the United States, as shown by the tonnage of fruit raised, value of the crop, carlot shipments, and quantities exported. Most of the apples are moved in the autumn, with the peak of the movement in October and November, as shown by data for 1918 to 1923 compiled by the Bureau of Agricultural Economics, United States Department of Agriculture.[2] However, considerable quantities are shipped in the colder months, and are thus liable to be exposed to low temperatures in transit. Consequently, very considerable losses are suffered by the apple industry every year from freezing in transit.[3] To this may be added the injury in cold and common storage houses when the temperature is allowed to fall below the freezing point of the fruit and to remain so for some time; also the injury from freezing when the fruit is still on the tree, which causes heavy losses in some districts. Detailed figures on the latter two sources of loss are as yet unavailable.

In spite of the importance of the apple industry, and the serious losses rendering protection for the fruit a matter of imperative necessity, the literature of the freezing problem as related to fruits has but few references to the apple.

Müller-Thurgau (*7*)[4] and Molisch (*6*) both made the observation that ripe apples may be exposed to a somewhat lower temperature without injury when thawed slowly than when the defrosting proceeds rapidly, but Chandler (*1*) was not able to demonstrate this for unripe apples.

Greene (*3*) reported experiments to determine the effect of freezing upon the keeping qualities of apples in cold storage, and to fix the temperature below which injury to apples could be expected to occur. He concluded that apples frozen on the tree could be stored safely provided the freezing was not too severe, that favorable weather followed it, and that thawing of the fruit had taken place gradually on the tree; also that apples frozen in cold storage at 24° F. or higher would show no injury if thawing took place gradually from 29° to 31°.

The investigations reported in the present article deal with determinations of the freezing points of most of our important commercially grown varieties of apples, with a study of undercooling and its relation to injury, and a determination of the effect of freezing on such matters as bruising of the fruit, visual injury, and keeping quality in storage, together with a discussion of the rate of cooling down and of freezing of apples in different types of packages under constant freezing conditions.

[1] Received for publication March 11, 1924—issued January, 1925.

[2] Carlot shipments of apples in the United States for the months September to February of the years 1918 to 1923, inclusive:[5]

Year	September	October	November	December	January	February
1918–19	8,070	26,680	13,563	6,320	4,044	3,679
1919–20	12,259	32,666	15,854	5,301	4,393	4,419
1920–21	11,043	37,284	23,087	8,875	6,046	6,698
1921–22	13,146	35,117	14,464	5,991	4,189	4,683
1922–23	14,787	32,052	19,512	8,229	8,438	6,257

[5] Data compiled by the Bureau of Agricultural Economics, U. S. Department of Agriculture.

[3] ROSE, D. H. DISEASES OF APPLES ON THE MARKET. U. S. Dept. Agr. Bul. 1253.

[4] Reference is made by number (italic) to "Literature cited," p. 127.

The apples used in these experiments were grown in various parts of the country, including the Pacific Northwest, California, New York, and the Maryland-Virginia apple district. A considerable number came from the orchards of the experimental farm at Arlington, Va. The varieties studied have been chosen primarily with reference to their commercial importance and are as follows: Yellow Newtown, Ben Davis, Grimes Golden, Delicious, Winesap, Rome Beauty, Esopus Spitzenburg, Jonathan, Wagener, York Imperial, Rhode Island Greening.

The methods followed in reading temperatures were similar to those employed in other fruit and vegetable freezing investigations (*4*, *10*, *11*). Temperature readings were obtained by means of single-junction copper-constantan thermocouples, of the type described by Taylor (*9*), in connection with a potentiometer and a galvanometer.

Some apples were frozen in metal cylinders immersed in an ice-salt bath, the fruit resting on cotton supported by a rack. The temperature of the air surrounding the fruit was read by a thermocouple suspended above and beside the fruit. Other apples were laid on dry boards in a freezing room held at constant temperature and frozen, the thermocouples being inserted in the usual way. A 10-junction thermocouple hung beside the apples exposed in the room. In all cases, however, the whole apple was subjected to the low temperature, the thermocouple being so inserted that its tip was located near the center of the fruit without being in the seed cavities.

Inoculation of the apples was effected by rapidly thrusting in and out of the fruit four or five times the thermocouple which had already been inserted in order to read the internal temperature. The term "inoculation" is used in this connection to mean any disturbance which will start crystallization of water, or ice formation, in the fruit. This caused a disturbance in the undercooled water films surrounding the thermocouple and brought on ice formation. It was found to be a more satisfactory method than tapping or bumping the fruit, since apples were sometimes inoculated with difficulty, even while considerably undercooled, and there was danger of serious bruising if they were inoculated by the latter means.

After freezing, the apples were removed from the cold room or freezing bath and placed in storage or subjected to the various treatments described later.

EXPERIMENTS AND RESULTS

FREEZING POINTS OF DIFFERENT VARIETIES OF APPLES

A considerable number of freezing-point determinations, made on different varieties of apples, has already been published (*12*).

TABLE I.—*Average and extreme freezing points of apples*

Varieties	Temperatures		
	Average	Minimum	Maximum
EASTERN GROWN	° F.	° F.	° F.
Baldwin	29.0	28.8	29.4
Ben Davis	28.6	28.2	29.0
Delicious	28.5	28.2	29.1
Grimes Golden	29.0	28.8	29.1
Jonathan	28.3	27.8	28.7
Paragon	28.5	28.5	28.6
Rambo	28.6	28.3	28.9
Stayman Winesap	28.5	28.0	28.9
Winesap	28.2	27.9	28.7
Yellow Newtown	28.0	27.8	28.2
York Imperial	28.3	28.1	28.5
WESTERN GROWN			
Delicious	28.4	28.0	28.9
Gano	28.6	28.3	29.1
Grimes Golden	28.6	28.3	29.1
Jonathan	28.4	28.0	28.7
Rome Beauty	28.9	28.7	29.4
Esopus Spitzenburg	28.7	28.3	29.1
Winesap	28.2	27.9	28.4

The data in Table I show some differences when varieties grown in the same region are compared, and also that the same variety grown in different parts of the country may show a slight variation in its freezing point. In some cases it has been found that the freezing point of a variety differs slightly from year to year with the same strain of apple grown in the same locality. These variations, due to climatic and other environmental differences while the apples are growing, are important in the study of the exact causes and results of freezing injury. The variation of a fraction of a degree does not warrant any change in the storage treatment of the fruit.

UNDERCOOLING AND ITS RELATION TO INJURY

It has been shown (*4*, *5*, *7*, *11*) that plant organisms like potatoes and tomatoes can be undercooled several degrees below their true freezing point, and then warmed again above their freezing point without freezing injury, providing no ice formation takes place within

the tissues. Müller-Thurgau was the first to insist that ice formation in the tissues was a necessary precedent to injury, and this opinion is held quite generally. It seems true, also, that a certain amount of ice formation can occur in apples (*6*) without injury. In other words, there must be a distinction made between apples which are frozen and those which are frozen to death, as apparently there are various degrees of freezing injury in frozen apples.

In the undercooling experiments, apples of several varieties were subjected to low temperatures and left undisturbed, so that undercooling took place. Temperatures were read at intervals until the desired low temperature had been reached, after which the apples were removed and allowed to become warm without ice formation ever having taken place.

TABLE II.—*Data showing temperatures to which apples were undercooled, temperature of the air surrounding the apples, and number of apples showing visual injury*

Temperature to which undercooled	Air temperature at undercooling	Visual injury
WINESAP FROM YAKIMA, WASH.		
°F.	°F.	
23.5	20.7	None.
23.5	20.6	None.
23.5	20.4	None.
23.4	23.0	None.
23.4	23.0	None.
23.0	22.4	None.
22.8	20.4	None.
22.6	20.4	None.
22.6	17.1	None.
22.5	19.6	None.
22.3	19.2	None.
22.2	20.4	None.
22.2	20.4	None.
22.0	20.5	None.
21.8	18.0	None.
21.5	20.5	None.
21.3	20.0	None.
21.2	15.5	(a)
21.0	15.0	None.
20.2	20.0	None.
20.2	20.0	None.
YELLOW NEWTOWN FROM HOOD RIVER, OREG.		
25.0	23.0	None.
25.0	22.6	None.
25.0	22.5	None.
25.0	22.3	None.
25.0	21.3	None.
24.7	23.0	None.
24.0	23.6	None.
24.0	23.0	None.
24.0	22.9	None.
YELLOW NEWTOWN FROM HOOD RIVER, OREG.—Continued		
°F.	°F.	
24.0	22.2	None.
24.0	21.9	None.
23.8	22.8	None.
23.4	23.0	None.
23.4	23.0	None.
23.0	22.4	None.
23.0	22.3	None.
23.0	22.2	None.
23.0	21.4	None.
22.9	22.4	None.
22.6	21.9	None.
22.5	21.9	None.
22.5	21.9	None.
21.8	------	None.
21.6	------	None.
20.3	16.5	None.
DELICIOUS FROM OPPORTUNITY, WASH.		
22.2	21.8	None.
22.0	21.8	None.
21.9	21.8	None.
19.8	15.2	(a)
GRIMES GOLDEN FROM ARLINGTON, VA.		
23.7	23.6	None.
23.1	22.3	None.
ROME BEAUTY FROM ARLINGTON, VA.		
22.2	21.4	None.
22.7	21.4	None.

[a] Some injury not near thermocouple.

With two exceptions, no injury resulted, and in these the damaged area was not immediately adjacent to the thermocouple. Examination of supposedly frozen apples has shown that there may be frozen areas in various parts of the fruit, separated by areas in which apparently little or no ice has formed. If the thermocouple is located in one of the latter, it may not record exactly the condition of ice formation throughout the apple. Though no visual injury was apparent in such apples, changes which could not be detected by careful inspection might nevertheless be taking place. The low temperature to which apples can be undercooled without injury, provided they are not disturbed, is very striking. Inoculation of apples sometimes takes place with comparative difficulty, so it is possible to bring their temperature seven or eight degrees below their freezing points and to hold them there for some time without the formation of ice. Since apples in transit are subjected to motion most of the time, the possibility of any considerable undercooling is slight. As the temperature drops below their freezing points it may be that such apples begin to freeze gradually, possibly by successive inoculations or disturbances producing small increments of ice in the tissues. Such a phenomenon is occasionally observed in apples which are entirely undisturbed, but this involves other causes not now definitely known.

EFFECT OF UNDERCOOLING AS DETERMINED BY THE PRESSURE-TEST METHOD

Since data from other experiments show that one effect of freezing apples is to make them softer and more mealy, apples of two varieties were undercooled and tested with a pressure-testing apparatus similar to that described by Murneek (*8*), which determines the hardness of the fruit. In tests with this apparatus the skin of the apple was removed from an area of about three-quarters of an inch in diameter at three equidistant points about the circumference of the fruit, and the test made of the number of pounds of pressure required to force a smoothly rounded plunger seven-sixteenths of an inch in diameter into the flesh of the fruit for a distance of five-sixteenths of an inch. Tests were also made on the same apples with the skin intact; but it has been found that tests directly on the flesh of the apple are a more accurate index of the real condition of the fruit as regards rela-

tive softness. The skin and its relation to the tissues directly underneath constitute variable factors which may mask the true condition of the apple.

Apples of two varieties, Yellow Newtown and Ben Davis, were used in these tests, 15 of each being brought to undercooling points ranging from 25.1° F. to 25.8° for the Yellow Newtown and from 24.7° to 25.8° for the Ben Davis. The temperature of the freezing room ranged from 22.1° to 22.7°. After undercooling, the apples were removed to a 70° chamber, where they remained for 24 hours, as did also lots of fruit which had not been undercooled. Pressure tests were then made on these lots and on a collateral lot removed directly from cold storage. The freezing points of these two lots of apples were 28.8° for the Yellow Newtown and 29.0° for the Ben Davis.

In undercooled fruit there is apparently no change which can be detected by the pressure-test method. No appreciable differences could be detected between undercooled fruit and that not undercooled, either when the tests were made immediately after undercooling, or after an interval in cold storage following undercooling.

FREEZING INJURY AS VISUALLY DETERMINED

The most obvious results of freezing are discoloration of the tissues of the apples, or the appearance of discolored spots on the surface, and these aspects of injury have received most consideration in the past. They are most important in the diagnosis of freezing injury, although there are other changes of importance in determining keeping qualities and market value after storage.

DIAGNOSIS OF FREEZING INJURY BY VISUAL MEANS.—The diagnosis of freezing injury in apples from the examination of sample specimens, and the determination of previous temperature conditions by such means, present considerable difficulty at times because visual symptoms of freezing injury resemble the so-called physiological breakdown in apples, which is induced by entirely different causes. In such doubtful cases, judgment as to the cause of injury will be modified by any knowledge of the previous history of the fruit. It is essential to consider a number of factors, none of which alone may give certain indication that freezing injury has occurred.

For purposes of rapid diagnosis of freezing injury where hundreds of apples were cut and examined, the severity of the injury was grouped under six heads: None, trace, slight, medium, bad, and very bad. These facilitated estimation of the damage found on cutting the apple, but were themselves classed into larger groups: No injury, trace, or severe injury. The first three headings comprised such fruit as had no injury, or only a relatively unimportant amount. It must be emphasized, however, that visual injury is not the only factor demanding consideration, especially in apples intended for storage, and that apples apparently uninjured may still have undergone changes tending to reduce their storage life.

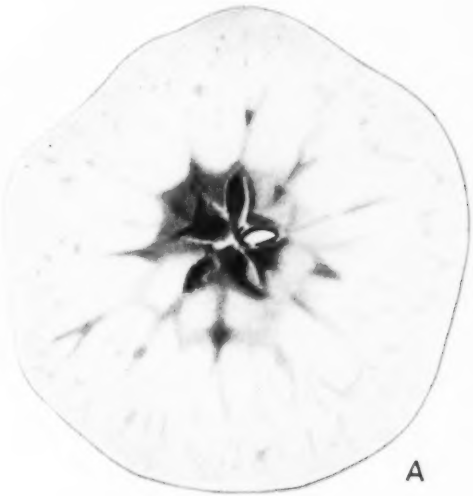
Slight freezing may occur and leave only a trace of visual injury or none at all, while exposure to very low temperature may so damage the fruit as to destroy its market value. Freezing injury which can be seen may occur in the interior of the fruit and be discovered only upon cutting the apple, or may appear on the surface. These two types of injury may appear independently, or may be found on the same fruit as, for instance, when a severely frozen apple takes on a "baked" appearance. In such a case, the interior may be wholly discolored and mushy, and show other distinctive features which will be described below. In addition, there is an indirect freezing injury due to bruising of the fruit while in the hard-frozen state, the resulting bruises being very much more serious than ordinary bruises.

VISUAL FREEZING INJURY OCCURRING IN THE INTERIOR OF APPLES.—Internal discoloration occurs in two more or less distinct types. In general, when freezing has not been severe and the whole apple tissue is not involved in the breakdown, there is a discoloration of the fibro-vascular system, usually brown, similar to that occurring in frozen potatoes. In cross sections this gives the appearance of brown dots; where a fibro-vascular strand is exposed longitudinally it is seen as a brown line. In Plate 1, A and B, are shown reproductions of water color

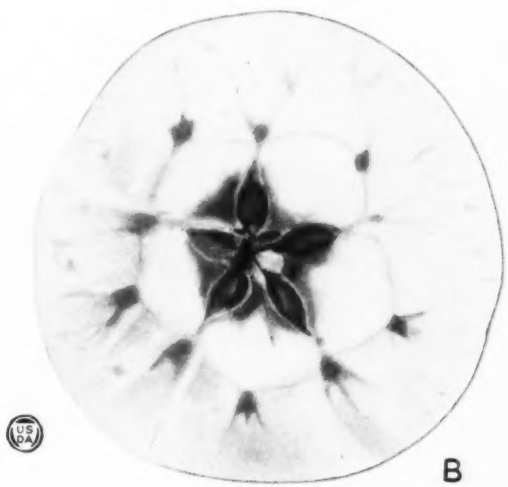
EXPLANATORY LEGEND FOR PLATE 1

A.—Cross section of Delicious apple, grown in Washington, showing discoloration of the cortex and secondary fibro-vascular bundles rather characteristic for the variety. The brown portions in the core are probably not freezing injury. A rather severly frozen specimen.

B.—Cross section of Winesap apple, grown in Virginia, showing strong discoloration of the primary fibro-vascular bundles, and also tissue discoloration frequently found in this variety. A rather severely frozen specimen.

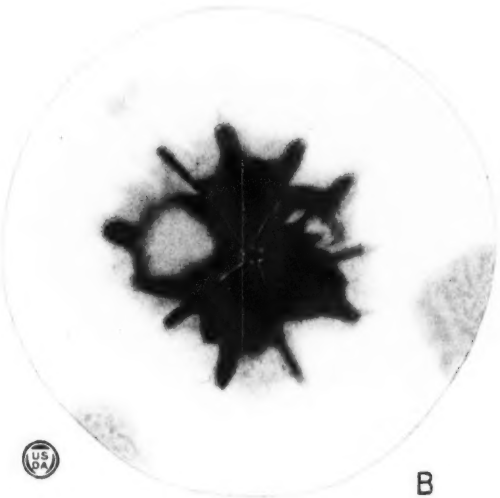


A



B

A



B

paintings made from cross sections of a Delicious and a Winesap apple, which are representatives of this type of injury. In Winesap apples, particularly where the secondary fibro-vascular system seems to have a considerable development just beneath the skin, a well-defined net necrosis may often be observed when the skin is peeled off without cutting too deeply into the flesh. Lens examination of thin sections of such apple tissue shows the apple cells generally clear and translucent, and the discoloration in varying tones of brown affecting only the cells of the bundles or those cells immediately adjacent. This fact applies equally to the primary bundles usually seen as large dots in concentric circles around the carpels, and to the secondary bundles scattered through the tissue; but both types of bundles do not necessarily show discoloration in the same apple. This may also be said of discoloration of the cambium, which appears as an entire concentric ring about the carpels and at times seems to join the primary fibro-vascular bundles, as shown in Plate 2, A. Discoloration of all of these may appear in the same apple; in other specimens discolorations may appear alone or in connection with other types of injury.

Discoloration of other interior tissue than the bundles or cambium frequently is found. For some varieties it is evidence that the degree of freezing has been more severe than that producing the injury described above. For others it is the characteristic reaction to any temperature sufficient to produce injury, and here vascular or cambial discoloration may be masked or entirely absent (Pls. 2, B; 3, A and B). This general discoloration of the tissue exhibits all degrees of intensity and when most pronounced marks the severely frozen apple. In some apples, there is in addition a marked softening and a mushy watery appearance; in others the flesh of the apple seems dry and mealy. The tissue resembles that in a state of decay and is wholly discolored, generally in tones of brown, not uncommonly with yellow or green hues. Sometimes quite brilliant blotches of color occur; or clearly defined lighter colored lines radiate from the center; and the cambial region may stand out as a deeply colored area.

VISUAL FREEZING INJURY OCCURRING ON THE SURFACE OF APPLES.—Surface injury other than that due to bruising while frozen consists of discoloration of the surface layers of cells and is usually quite shallow. One of the two usual forms consists of a brown skin discoloration with poorly defined edges resembling a bruise except for a certain water-soaked appearance (Pl. 4, A). This injury is sometimes mistaken for soft scald, but is quite different, because the lesions of soft scald are definite in outline, dull in color, and somewhat sunken in a late stage. The other common form of surface injury occurs only on red apples or on the blushed side of the fruit. (See Pl. 4, B.) It is a yellowish-brown discoloration resembling in some cases the work of leaf-miner larvae in leaves. More often it appears as small discolored areas, very irregular in outline but rather clearly defined. In storage these areas may remain quite intact, or they may become more or less sunken, enlarged, and of a dark brown color. This enlargement seems caused by death and discoloration of cells adjacent to those showing injury very soon after freezing has taken place. In many Winesap apples the tissue immediately beneath such places had dried completely after a storage period of three months, and had been replaced by cavities sometimes 10 mm. in depth, lined with brown corky tissue composed of dead cells. To some degree these cavities resemble the drought cracks occasionally found in apples like the York Imperial, and probably are caused by an increased water loss from the frozen tissues.

Since the intercellular spaces have intimate connection with the lenticels or corky openings in the skin, the loss of water vapor is augmented above the ordinary amount. The greater tendency to wilting and to rapid water loss is characteristic of frozen apples thawed under conditions favoring the removal of moisture from the fruit. Apples frozen to a certain degree may also have a water-soaked appearance, and a skin tough and resilient to the touch. As a general rule, surface discoloration due only to freezing is very shallow. In varieties with a green color, notably the Yellow Newtown, it often occurs before other visual freezing injury can be de-

EXPLANATORY LEGEND FOR PLATE 2

A.—Cross section of Grimes apple, grown in Virginia, showing discoloration of the carpel and cambial regions, and of the primary fibro-vascular bundles. A rather severely frozen specimen.

B.—Cross section of Ben Davis apple, grown in Virginia, showing discoloration of the central portion of the fruit. The brown areas near the periphery are probably bruises made while the fruit was in a hard frozen condition. A rather severely frozen specimen.

tected, and detracts from the appearance of the fruit, injuring its market value. Yellow Newtown apples so affected may appear to have been subjected to very severe bruising while in the hard frozen state.

TIME OF APPEARANCE OF VISUAL INJURY IN FROZEN APPLE TISSUE.—The discoloration of apple tissue which follows a certain degree of freezing is generally not visible while the fruit is still frozen. As thawing proceeds, it becomes more and more evident. Where freezing is not severe it may increase in degree, and to a lesser extent in area, as the ice in the tissue melts (Table III).

TABLE III.—*Effect on Yellow Newtown apples (in lots of 10) of varying periods of exposure to 15° F., and of different periods of storage at 40° and 65° after freezing*

Period of exposure	Number of apples showing injury in—			
	5 hours	8 hours	13 hours	90 hours
Hours	SUBSEQUENT STORAGE AT 65° F.			
3	0	0	0	4
6	2	2	*4	*5
25	10	10	10	10
47	10	10	10	10
73	10	10	10	10
	SUBSEQUENT STORAGE AT 40° F.			
3	0	0	*1	*2
6	0	*1	*2	*5
25	*3	*3	*7	10
47	0	*5	10	10
73	0	*7	10	10

* Slight injury only.

From Table III it is evident that the severity of the injury to Yellow Newtown apples exposed for the shorter periods increases with the length of the storage period. It seems improbable, however, that it increases materially when the ice in the tissue has entirely melted; where such increase occurs it may be due to secondary influences in tissues weakened by freezing rather than to killing by the formation of ice. Thus it is apparent that when moderate freezing injury has occurred, it is impossible to determine accurately the amount of injury until a considerable interval of time has elapsed following thawing.

The term "baked" or "cooked" is frequently given to very severely frozen apples which break down completely, actually presenting the brown, wrinkled appearance of an apple subjected to high temperature. Such surface injury is readily recognized.

EFFECT OF BRUISING FROZEN APPLES

The bruising of hard frozen apples results in a much more serious injury than that produced by similar bruising of unfrozen fruit. Some experiments were made to determine in what respects such bruises made while the fruit was frozen differed from the ordinary bruises; whether the freezing of bruises already present changed their appearance and depth; and whether the temperature of thawing had an effect on the seriousness of the bruise as measured by its depth.

The apple to be bruised was held on its side on the platform of a weighing scale having a capacity of 50 pounds. A flat surface was brought in contact with the upper side of the fruit and pressure applied until the pointer on the dial recorded the desired figure in pounds. The apple was then turned and pressure again applied, thus producing four bruises fairly equally spaced about the circumference. While this does not give exactly the type of bruise encountered where the fruit has been subjected to jolting or bumping or has received sudden sharp blows rather than more prolonged pressure, it was found satisfactory for the investigation of certain features of this problem. After further storage or treatment, the apple was cut across the middle horizontally and the depth of the bruises determined in millimeters. The greatest distance to which the discoloration had penetrated was taken as the depth of the bruise. The sample lots consisted of 10 apples each having 4 bruises, and the data presented in Table IV are, in each case, averages of the maximum depth of 40 bruises.

DIFFERENCES IN APPEARANCE OF BRUISES ON HARD FROZEN AND ON UNFROZEN APPLES.—Bruises made on apples while frozen differ in several respects from those on unfrozen fruit. The bruises in hard frozen apples have a greater depth and are conical in shape with the apex reaching nearer to the

EXPLANATORY LEGEND FOR PLATE 3

A.—Cross section of Yellow Newtown apple, grown in Washington, showing extensive discoloration involving the tissue cells, and rather characteristic of this variety. A bruise discoloration is found near the periphery. A rather severely frozen specimen.

B.—Cross section of Grimes apple, grown in Virginia, showing extensive tissue-browning as well as discoloration of the cambial and carpel regions. A severely frozen specimen.

A

B

A
B

middle of the fruit than on apples similarly bruised while unfrozen. Bruises in frozen apples have a more indefinite outline and a more complete wrecking of the tissue organization as shown by the character of the discoloration.

In the ordinary bruises in unfrozen fruit lines of cleavage tend to appear in the bruise approximately parallel to the surface, and these are often separated by strips of apparently uninjured tissue. This feature is never found in the bruise made on hard-frozen fruit. It may be that, whereas pressure on unfrozen tissue causes the cells to separate along the weakest lines, similar pressure on hard-frozen tissue with the intercellular spaces filled with ice crystals might entirely crush and rupture the tissue organization. Examined through a hand lens by transmitted light, thin sections of bruised tissue on hard-frozen fruit show many clear translucent areas. When surrounded by discolored tissue they appear brown by reflected light. They apparently represent portions of the tissue in which the ice crystals completely obliterated the cell structure, and the cavities filled with water when the ice melted. The ordinary bruise in cross section has a dry, corky appearance while the bruise made on hard-frozen fruit appears more watery.

The surface appearance of the bruise before the apple is cut will sometimes give a clue to the conditions under which the bruise occurred, that made on frozen fruit having a more water-soaked appearance and being softer and less resistant to pressure by the fingers than a bruise in unfrozen fruit. Old bruises on fruit which was afterwards frozen do not differ appreciably in appearance from the ordinary bruises on apples not subsequently exposed to freezing temperatures. Plate 5, A and B, shows bruises made on frozen and unfrozen Yellow Newtown apples. Examination of the bruises is oftentimes a very great aid to the diagnosis of freezing injury.

EFFECT OF BRUISING WHILE HARD FROZEN.—Bruises were made on apples of different varieties while hard frozen, unfrozen lots bruised with exactly th same pressure being measured or comparison. The apples were fro en by exposing them 24 hours to tempe atures around 22° F., and were thaw by placing them at 68° for another 24-hour period (Table IV). It will be seen that the injury in general, as measured by the depth of the bruise was about twice as severe in apples bruised when hard frozen as in unfrozen apples. The damage to their appearance is much more serious, and likely to cause marked depreciation in their market value.

TABLE IV.—*Comparison of the depth of bruises in frozen and unfrozen apples, with pressure applied for bruising*

Variety	Pressure applied for bruising	Bruise depth		Ratio of depth of frozen to unfrozen bruises
		Unfrozen	Hard frozen	
	Lbs.	*Mm.*	*Mm.*	
Baldwin	50	7.3	14.1	1.9
Rome Beauty	30	6.0	14.2	2.4
	50	9.5	17.5	1.8
Esopus Spitzenburg	50	5.1	15.3	3.0
Winesap	50	6.3	14.0	2.2
Yellow Newtown	30	6.7	16.8	2.5
York Imperial	50	6.2	12.8	2.1

EFFECT OF THE PRESENCE OF DIFFERENT AMOUNTS OF ICE UPON THE SEVERITY OF INJURY FROM BRUISING.—The presence of ice is presumably the cause of augmentation of injury when hard-frozen fruit is bruised. Tests were made with apples which were hard frozen and then bruised in different stages of thawing. Comparisons were made with lots of apples bruised while hard frozen and also with those bruised when unfrozen (Table V).

Damage by bruising is obviously lessened as the ice in the tissues melts. When it has entirely disappeared, bruising of the tissues produces injury only slightly more severe than that caused by a similar bruising of unfrozen fruit, at least so far as concerns the depth of the injured tissue. Tests made with other varieties than Rome Beauty gave similar results, indicating that frozen apples should be allowed to thaw before they are moved. The bruises suffered in handling will then be, at the most, only slightly more serious in depth and character than if the fruit had not been frozen at all.

EXPLANATORY LEGEND FOR PLATE 4

A.—Surface view of Yellow Newtown apple, grown in Washington, showing epidermal discolorations rather characteristic of green-skinned varieties and especially Yellow Newtown, and not necessarily caused by bruising.

B.—Surface view of Delicious apple, grown in Washington, showing epidermal discoloration rather characteristic of red-skinned varieties.

However, there is some indication that frozen apples stored undisturbed for an extended period in the original position after thawing will suffer somewhat deeper and more serious bruises when moved than unfrozen fruit similarly stored. Freezing, even if unaccompanied by visual injury, tends to soften the fruit, making it less resistant to injury after an extended storage period. But the severity of injury is not nearly so great as in fruit bruised while hard frozen.

TABLE V.—*Comparison of the effect of bruising unfrozen and partially frozen Rome Beauty apples as shown by the depth of the injured portion when thawed*

Treatment	Bruise depth	Ratio of depth of frozen to unfrozen bruises
30 POUNDS PRESSURE APPLIED FOR BRUISING		
	Mm.	
Unfrozen	6.0	
Bruised hard frozen	14.2	2.4
Thawed 1 hour at 68° F	13.4	2.2
Thawed 3 hours at 68° F	8.0	1.3
Thawed 5 hours at 68° F	7.8	1.3
Thawed 7 hours at 68° F	7.7	1.3
Thawed 24 hours at 68° F	7.0	1.2
Thawed 7 hours at 40° F	10.9	1.8
Thawed 24 hours at 40° F	7.5	1.3
Thawed 48 hours at 40° F	6.6	1.1
50 POUNDS PRESSURE APPLIED FOR BRUISING		
Unfrozen	9.5	
Bruised hard frozen	17.5	1.8
Thawed 1 hour at 68° F	17.4	1.8
Thawed 3 hours at 68° F	12.3	1.3
Thawed 5 hours at 68° F	12.9	1.4
Thawed 7 hours at 68° F	12.0	1.3
Thawed 24 hours at 68° F	10.3	1.1
Thawed 7 hours at 40° F	14.6	1.5
Thawed 24 hours at 40° F	11.0	1.2
Thawed 48 hours at 40° F	10.7	1.1

EFFECT OF FREEZING ON DEPTH OF BRUISES ALREADY PRESENT.—Yellow Newtown apples were used in experiments to obtain data upon the effect of freezing apples which were already bruised. The fruit was subjected to temperature and handling conditions similar to those followed in the other bruising experiments, but before being frozen it was stored for certain periods after bruising (Table VI).

TABLE VI.—*Effect of freezing upon depth of bruises previously made with 30 pounds pressure on Yellow Newtown apples*

Treatment after bruising	Storage temperature after bruising	Length of storage period	Bruise depth
	°*F.*	*Days*	*Mm.*
Frozen	70	1	6.7
Unfrozen	70	1	6.0
Frozen	70	3	6.6
Unfrozen	70	3	6.6
Frozen	70	6	6.1
Unfrozen	70	6	6.1
Frozen	40	14	6.0
Unfrozen	40	14	6.0

There is no indication that bruises made before the fruit was frozen become more serious in depth when the fruits are subsequently frozen, nor that they change in appearance. Tests with other varieties gave similar results.

EFFECT OF DIFFERENT THAWING TEMPERATURES ON DEPTH OF BRUISES ON HARD FROZEN FRUIT.—To determine what effect the temperature at which fruit is held while thawing has on the injury from bruises, a number of Esopus Spitzenburg apples were frozen hard, and bruised as already described. The fruit was then thawed at various temperatures from 32° to 70° F.

No significant differences appear in the depth of bruises made on hard-frozen fruit when it is subjected to various thawing temperatures (Table VII).

DETERMINATION OF THE INTERNAL TEMPERATURE AT WHICH VISUAL INJURY TAKES PLACE IN FROZEN APPLES

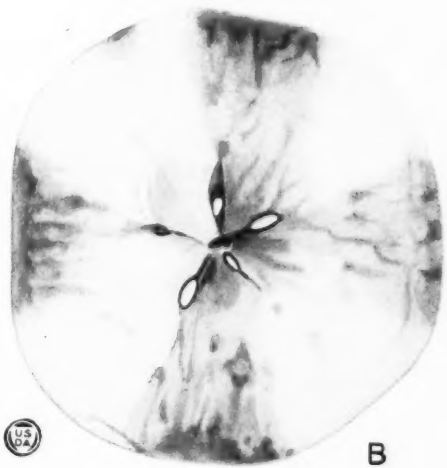
Certain peculiarities in the reaction of apples to supposedly fatal temperatures have been noted in reading the temperature by means of the thermocouples. Apples quite similar in weight and appearance show marked variations in the rate of cooling and of freezing, and exhibit the most diverse phenomena in visual injury. Experiments were made to test the hypotheses, repeatedly noted, that ice formation is not in itself necessarily injurious to the fruit but that apparently a certain

EXPLANATORY LEGEND FOR PLATE 5

A.—Cross section of Yellow Newtown apple, bruised while unfrozen by the application of 35 pounds of pressure to areas on its surface.

B.—Cross section of Yellow Newtown apple, bruised while hard frozen by the application of 35 pounds of pressure to areas on its surface, showing the severity made on hard-frozen tissue.

A



B

amount of ice formation is required before injury results. Freezing points of a large number of apples of a certain variety were determined. When this was accomplished the apples were allowed to remain in the freezing room and further records were made of their internal temperatures.

TABLE VII.—*Effect of different thawing temperatures on the depth of bruises made with 50 pounds pressure on hard frozen Esopus Spitzenburg apples*

Condition when bruised	Thawing temperatures	Duration of exposure to thawing temperatures	Bruise depth	Ratio of depth of frozen to unfrozen bruises
	° *F.*	*Hours*	*Mm.*	
Unfrozen	70	24	5.1	-------
Frozen	70	24	15.3	3.0
Do	70	48	15.0	-------
Unfrozen	70	72	5.0	-------
Frozen	70	72	16.8	3.4
Unfrozen	50	24	5.1	-------
Frozen	50	24	15.4	3.0
Do	50	48	14.0	-------
Unfrozen	50	72	6.0	-------
Frozen	50	72	16.2	2.7
Unfrozen	40	24	5.5	-------
Frozen	40	24	15.0	2.7
Do	40	48	19.3	-------
Unfrozen	40	72	5.1	-------
Frozen	40	72	14.9	2.9
Unfrozen	32	24	5.1	-------
Frozen	32	24	14.3	2.8
Do	32	48	13.4	-------
Unfrozen	32	72	5.1	-------
Frozen	32	72	14.8	2.9

The internal temperature in an apple exposed to freezing conditions usually drops below the freezing point, that is, it is undercooled. If the temperature is reduced enough, ice crystals begin to form, and the heat of fusion produced in the formation of the ice crystals raises the temperature of the apple to a point where it remains practically stationary, or with only slight reduction, until part of the water in the tissues which can be frozen out in the form of crystals of ice has been thus changed. The point at which the temperature remains constant is called the freezing point. After this is reached the temperature of the apple gradually becomes lower and approaches that of the room or environment of the fruit, where it can be held almost indefinitely after some minor fluctuations.

These fluctuations may be due to the further crystallization of small amounts of water which are forced from the liquid state by the increasing internal tension in the cells of the apple as the temperature continues to fall. Figure 1 shows a typical curve of the freezing of a Yellow Newtown apple, and illustrates the points mentioned above. A portion of the curve showing the temperature drop while the fruit was being cooled from the storage temperature of 34° F. has been omitted for the sake of brevity. The reactions of the fruit noted during and after the freezing process suggest that visual injury occurs when the temperature drops a certain distance below the freezing point. This injury is probably due to the loss of water from the protoplasm of the cells, which has been shown to occur during the freezing process. In other words, the internal temperatures measured as freezing goes on are an indirect measure of the amount of ice which has been formed; and this degree of ice formation may determine the occurrence of visual injury for any set of internal conditions in the fruit. It will be shown elsewhere that other changes also seem to occur in the fruit as soon as ice formation has taken place.

To obtain further information on the internal temperatures of frozen apples at which visual injury occurs, readings of the freezing point and of the internal temperatures when the fruit was removed from the freezing room have been collected, together with other relevant data. These are so voluminous that they are presented only in brief summary form to bring out certain facts (Table VIII).

The temperatures prevailing in the freezing room while the different lots were under observation did not vary widely for the three varieties. The maxima and minima were 22.3° F. and 21° for the Ben Davis, 22.7° and 21.9° for the Winesap, and 22.4° and 21.3° for the Rome Beauty. All the apples in this experiment were grown on Arlington Experiment Farm, Rosslyn, Va.

In the case of the frozen Ben Davis apples studied, Table VIII indicates in the average only a small amount of visual injury when the internal temperatures were 4° F. below the freezing point. Below this point the percentage of injury increased rather sharply, though not markedly, so that in the group where the temperature was 6.1° to 7° below the freezing point nearly two-thirds of the apples showed visual injury. No injury appeared in 14 apples of this variety when the internal temperatures dropped from 3.1° to 4° below their freezing points.

The internal temperature of frozen Winesap apples could not go so far below their freezing point without

TABLE VIII.—*The amount and degree of visual injury occurring in Ben Davis, Winesap, and Rome Beauty apples when their internal temperatures fall to different temperatures below their freezing point after freezing has taken place*[a]

Difference between freezing-point temperature and temperature at removal from freezing conditions, in groups of 1° F.	Freezing points			Visual injury in per cent			Total number of apples
	Average	Maximum	Minimum	None	Trace	Severe	
BEN DAVIS							
3.1–4.0° F.	28.8	29.1	28.6	100.0	0	0	4
4.1–5.0° F.	28.8	29.2	28.1	65.5	30.7	3.8	26
5.1–6.0° F.	28.9	29.4	27.8	36.9	44.7	18.4	65
6.1–7.0° F.	28.9	29.4	28.2	37.4	39.7	22.9	83
WINESAP							
2.5–3.4° F.	28.6	28.9	28.1	75.0	20.8	4.2	24
3.5–4.4° F.	28.3	29.0	27.6	62.5	25.0	12.5	8
4.5–5.4° F.	28.4	29.0	27.8	12.5	75.0	12.5	40
5.5–6.4° F.	28.6	29.0	27.9	0	40.5	59.5	37
ROME BEAUTY							
2.1–3.0° F.	29.5	29.9	29.0	70.6	29.4	0	17
3.1–4.0° F.	29.4	30.0	28.5	73.3	23.4	3.3	30
4.1–5.0° F.	29.1	29.8	28.3	90.7	7.0	2.3	43
5.1–6.0° F.	29.2	29.8	28.4	64.4	28.7	6.9	73
6.1–7.0° F.	29.2	29.7	28.0	30.9	42.8	26.3	42
7.1–8.0° F.	29.3	29.7	28.4	13.7	40.9	45.4	22

[a] The differences in temperature between the freezing point and the removal temperature of the apples, calculated to tenths, have been condensed into groups of 1° F. each. For instance, all the temperature differences of a magnitude from 3.1° and 4.0° appear in the group so designated.

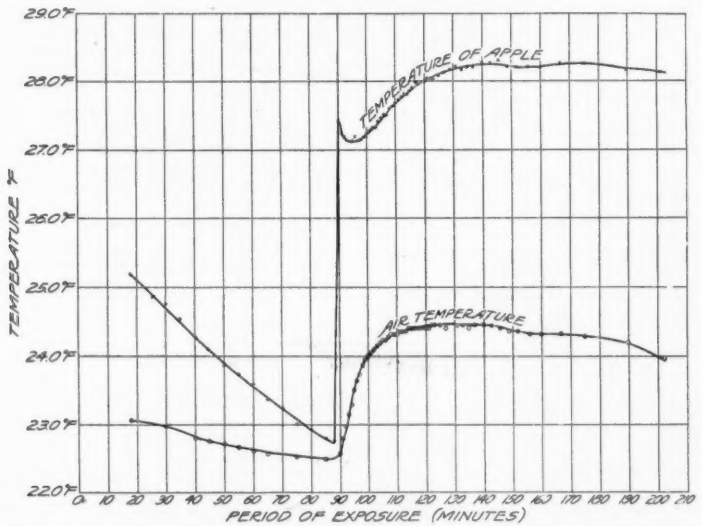


FIG. 1.—Internal temperature of a freezing Yellow Newtown apple exposed to low temperature conditions. Temperature of the air surrounding the fruit also given

injury. Even in the group in which the temperatures were between 2.5° F. and 3.4° below the freezing point, 25 per cent of the apples were injured. The number of injured apples and degree of injury increase greatly as the internal temperature drops farther below the freezing point.

Frozen Rome Beauty apples showed about 30 per cent slight injury when the internal temperature was only 2° to 3° below the freezing point. A temperature of 6° to 8° below the freezing point caused very severe visual injury.

Apparently there is a marked variation in the temperatures which different varieties of apples will endure without visual injury. Ben Davis will stand exposure to distinctly lower tempera-

tures than will Winesap and Rome Beauty. Under the conditions of this test, actual internal temperatures of 25° F. or lower were required to injure Ben Davis. An internal temperature of 26° resulted in some injury to Winesap, while 27° was sufficient to result in slight injury to Rome Beauty. Below these temperatures, injury increased markedly with successive decreases in temperature. The lower the temperature attained, the greater the quantity of ice formed in the tissues and the greater the apparent injury.

These temperatures represent about the range at which visual injury will first occur when the apples thaw rather slowly in air temperatures. Certain data subsequently secured indicate that with extremely rapid thawing, such as that induced by immersing the frozen apples in warm water, visual injury may occur at somewhat higher temperatures. Internal temperatures even one degree below the freezing point may result in injury if followed by extremely rapid thawing. For commercial conditions, however, where thawing would always be in air, actual fruit temperatures of 25° to 27° represent about the highest point at which visual injury may be expected to occur.

THE RATE OF COOLING DOWN OF BARRELS AND BOXES OF APPLES AT DIFFERENT FREEZING TEMPERATURES

It is reasonable to suppose that temperature curves showing the rate of cooling of fruit packed in various types of containers would differ under constant low temperature conditions outside the package. To obtain more evidence on this point, Winesap and York Imperial apples were exposed to freezing temperatures in barrels and in commercial apple boxes. The barrels were placed on end and the boxes were laid horizontally on a wooden floor rack 6 inches above the floor of the room. Part of the boxed apples were wrapped and part unwrapped. One series was run at about 25° F. and another at about 20°. The reduction in temperature within the packages was read by thermocouples every two or three hours during at least four or five days, and in some instances this was carried on at longer intervals to 12 days. In this way a complete history was secured of temperature changes in the fruit in different portions of the packages and in the surrounding air. The graphs presented in Figures 2 to 12 show the temperature changes occurring in the apples.[5]

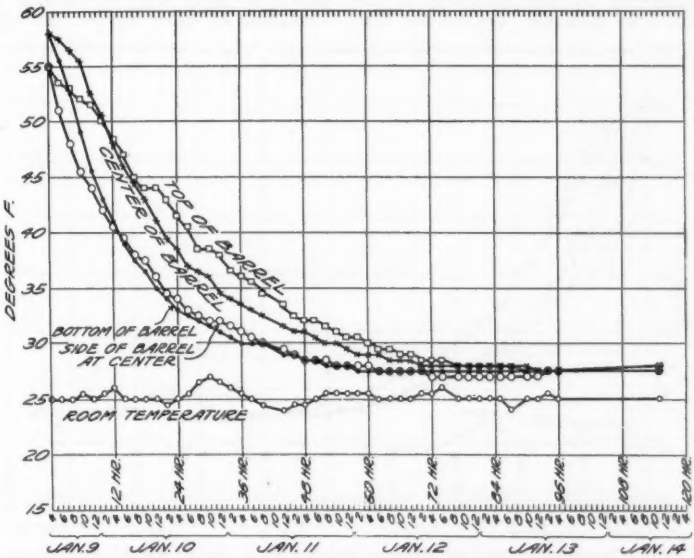


FIG. 2.—Temperatures obtaining in different parts of a barrel of unwrapped Winesap apples during exposure to external temperatures around 25° F. for 120 hours

[5] The preparation of the packages for these experiments was as follows: Two thermocouples were inserted in apples in each of the following locations in the packages: Barrel: Top, center, side at center and bottom. Boxes of wrapped and unwrapped apples: Top, center, and bottom. The two readings from the same location were averaged for better comparison of the data.

The temperature curves for Winesap apples packed in a barrel are presented in Figure 2. The room temperature was kept as near 25° F. as possible although some unavoidable variations occurred. It will be seen that the temperatures in all parts of the barrel drop rather rapidly at first, and when freezing begins the curves flatten out and the temperatures remain fairly constant for considerable periods of time with wholly insignificant variations. Undoubtedly this is the freezing point of the apples, not only a somewhat composite one for the particular fruit in which the thermocouple is inserted, but one influenced by the fact that adjacent apples are also

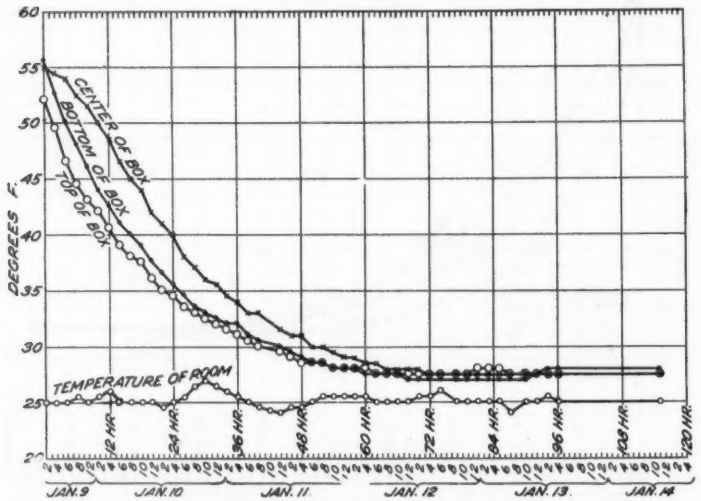


FIG. 3.—Temperatures obtaining in different parts of a box of wrapped Winesap apples during exposure to external temperatures around 25° F. for 120 hours

freezing. The heat of fusion produced by ice crystallization in these apples diffuses into the air spaces between them, mutually affecting the heat gradients existing between the exterior and interior tissues. Upon this heat gradient, which is itself a complex of other factors, depend the rate of further crystallization, the path of temperature curves, and even the injury and death of the tissues. It is a problem of great complexity and can be but briefly considered here.

It should be noted that there is no evidence of undercooling in the path of the temperature curves for the apples in the barrel. This does not mean that individual apples do not undercool under such conditions, for there is much reason to assume that they do. The visual injury to the fruit used in these experiments was not quantitatively determined; but apples with severe visual injury were found throughout different parts of the barrel. Probably these apples froze comparatively early in the period of exposure, since it has been shown that in general there must be a rather considerable temperature difference between their freezing point and the temperature at which injury commences. It is suggested that the heat of fusion given off by the early ice crystallization in these scattered apples may be sufficient to raise the temperature of any particular barrel location so as to delay the time of ice formation in other apples. In other words, some apples may be frozen, and the heat they give off during the process tends to delay the freezing of others.

The paths of the temperature curves for apples exposed in packages to low temperature generally show comparatively little undercooling before freezing commences. At any rate it has not been possible to carry the undercooling to the degree to which it has been shown to occur in isolated apples, surrounded on all sides by cold air, when these are not disturbed.

The data show further that the bottom and sides of the barrel cool most quickly, the top remains warm longest, and the center fruit in the barrel is intermediate in the rate of cooling. This is logical, since the heated air

naturally rises to the top, while the colder air being heavier, tends to settle into the bottom of the barrel. In addition, there is also heat conduction through the package, irrespective of convection currents within. A study of the results shows that it was two days before the bottom and sides of the barrel showed a steady temperature indicative of the freezing point, although some freezing undoubtedly occurred before that time. For fruit at center and top of the barrel another day passed before the freezing process was well under way.

The data for the boxed wrapped apples are presented in Figure 3, those for the boxed unwrapped apples in Figure 4. The fruit in these boxes was not packed according to any commercial pack, though regular commercial wraps were used. The general trend of the two groups of curves is strikingly different while the temperature is dropping to the freezing point of the fruit. The temperatures in the wrapped apples show a gradual decline, while those in the unwrapped apples show a sudden drop with some suggestion that undercooling took place previous to freezing. These differences will be brought out very clearly if the position of curves is noted at the same time periods. Wrapping the fruit noticeably retards heat loss when the package is exposed to freezing temperatures.

In order to show this comparative difference more easily, the temperature curves for the apples from the center of the barrel and from the center of the two boxes were plotted together and are given in Figure 5. The curves for the wrapped apples and the fruit in the barrel almost coincide. In one instance, the wrappers retarded heat loss from the center, in the other a greater amount of fruit intervening between the center and the exterior served a similar purpose. As the curve for the unwrapped apples differs considerably from the other two curves, it is especially interesting to compare the behavior of the two boxes of fruit. The interior temperature of the

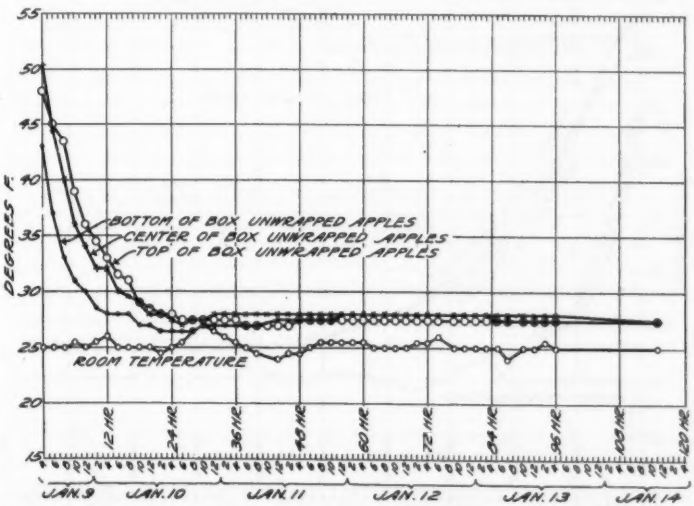


FIG. 4.—Temperatures obtaining in different parts of a box of unwrapped Winesap apples during exposure to external temperatures around 25° F. for 120 hours

wrapped apples indicates that freezing began in amounts sufficient to offset the heat losss to the exterior in about 64 hours. In the unwrapped apples it seems to have begun in such amounts in 32 hours, showing that wrapping the fruit retarded the beginning of freezing nearly a day and a half.

In Figure 3 there is an apparent discrepancy in the relative position of curves for the top, center, and bottom, in that the apples in the top of the box seem to have been the coldest. The apples in this experiment were wrapped and packed in the freezing room in order to place the thermocouples in their proper position. Since the apples in the top of the box were packed last, they were exposed unwrapped to

the low temperatures for the longest time. Consequently their initial temperature was lower and continued so. There seems to have been no considerable warming of the fruit in the upper layers by heat given off from apples in the interior of the box. The data are plotted in Figure 3 for only 120 hours, but the experiments were carried on for 12 days. At the end of this time the maximum drop from the freezing point in the bottom of the box of unwrapped fruit was only 1.5° F. In some instances, as for example the center of the box of wrapped apples, the temperature reading at 12 days was practically the same as it had

Figure 2. This is true also of the graphs for temperature changes in the boxes of wrapped and unwrapped Winesap apples compared with similarly handled York Imperial apples. No temperature readings were made in the centers of boxes of the latter. The data given in Figure 7 are for both wrapped and unwrapped York Imperial apples. It should be noted that the discrepancy in position of the temperature graph for the top of the box of wrapped Winesap apples is found only for a short time in the case of the York Imperial, after which the heat from the center of the box probably warmed the upper layers so that the temperature of

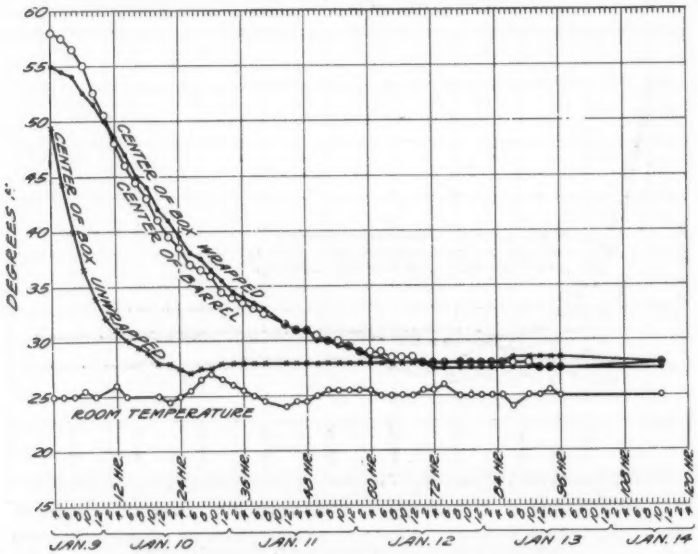


FIG. 5.—Comparison of the temperatures obtaining in the center of the box of wrapped, in the box of unwrapped, and in the barrel of unwrapped Winesap apples during exposure to external temperatures around 25° F. for 120 hours

been at 64 hours, indicating that ice formation in the fruit had been going on with the production of heat of fusion in amounts sufficient to offset the heat loss to the colder exterior. In nearly all cases, the temperature drop at the end of 12 days was a fraction of a degree below the temperature at which the fruit had been for a long time and which was apparently the freezing point.

Figures 6 and 7 present the data for the York Imperial apples packed and handled similarly to those of the Winesap variety. The graphs for the temperature changes in the fruit in the barrel closely resemble those shown in the top of the box thereafter was higher than that of the bottom.

Another series of experiments was carried on with a freezing-room temperature at or below 20° F., with general results similar to that at 25° F., the important difference being that the interior temperature of the packages drops more rapidly at the lower freezing temperature. Figures 8 and 9 give the results obtained for the two barrels of apples, Winesap and York Imperial, for a period of 96 hours. The fact that during the first few readings fruit in the top of the barrel is apparently colder than fruit in the center or at the bottom of the barrel is probably due to inci-

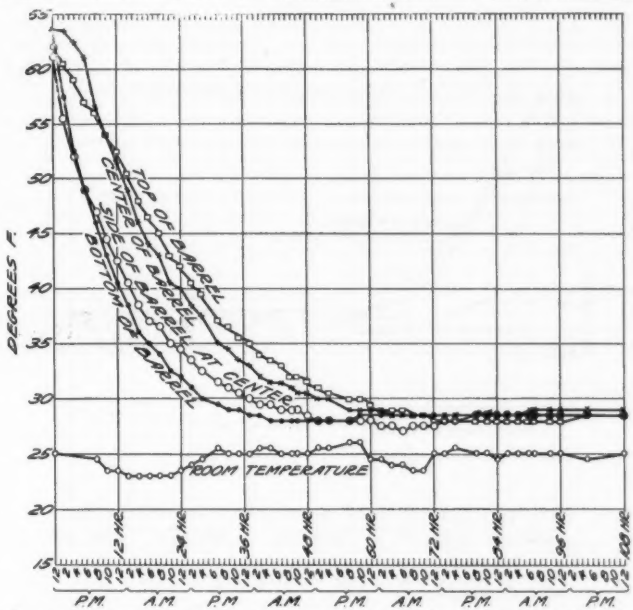


FIG. 6.—Temperatures obtaining in different parts of a barrel of unwrapped York Imperial apples, during exposure to external temperatures around 25° F. for 120 hours

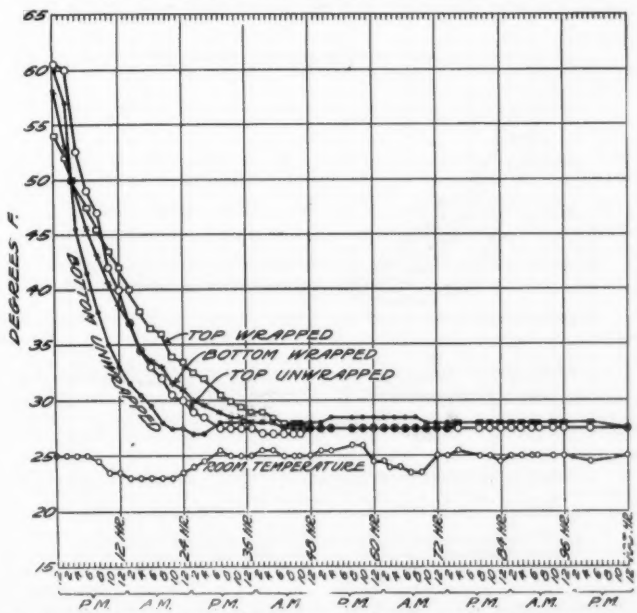


FIG. 7.—Temperatures obtaining in the upper and lower parts of a box of wrapped and a box of unwrapped York Imperial apples, during exposure to external temperatures around 25° F. for 120 hours

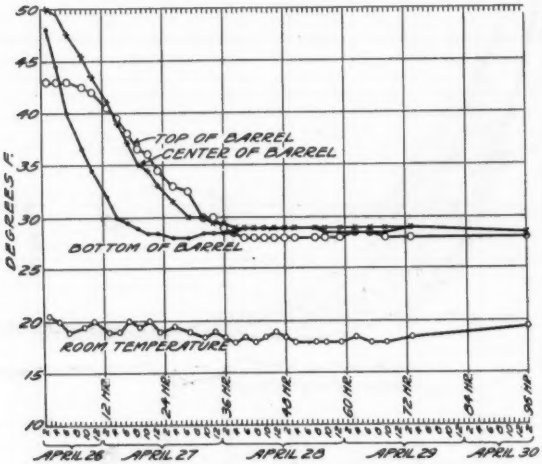


FIG. 8.—Temperatures obtaining in different parts of a barrel of unwrapped Winesap apples, during exposure to external temperatures at or below 20° F. for 96 hours

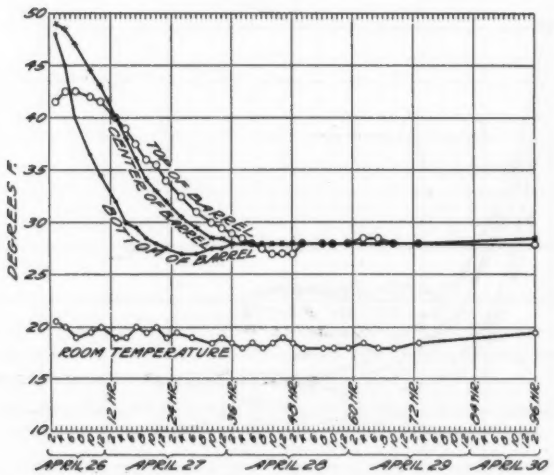


FIG. 9.—Temperatures obtaining in different parts of a barrel of unwrapped apples, during exposure to external temperatures at or below 20° F. for 96 hours

dents of packing, as mentioned above. After the first 16 hours the fruit in the top of the barrel is warmer than that elsewhere. Freezing began in the fruit at the bottom of the barrel after about 24 hours; in 12 more hours, or 36 hours from the beginning of the experiment, apples in the other positions also began to freeze.

For purposes of comparison the temperature curve for the bottoms of the two barrels of Winesap apples frozen at 20° F. and at 25° are presented together in Figure 10. Although the two initial temperatures are not the same, making exact comparison impossible, there is some indication of a more rapid rate of temperature fall in the bottom of the two boxes indicates that wrapping tends to equalize these differences, at least at the exterior temperatures prevailing during the experiment, and to make the temperature more uniform throughout the box. In the box of unwrapped apples freezing took place in amounts sufficient to influence the temperature curve not long after 12 hours. While there is some indication of freezing between 24 and 36 hours in the wrapped apples, the temperature curves do not assume a more permanent horizontal direction until 42 hours.

The relative lengths of time for which the temperature curves for the bottom of the boxes remain horizontal, or at the freezing point, should be noted.

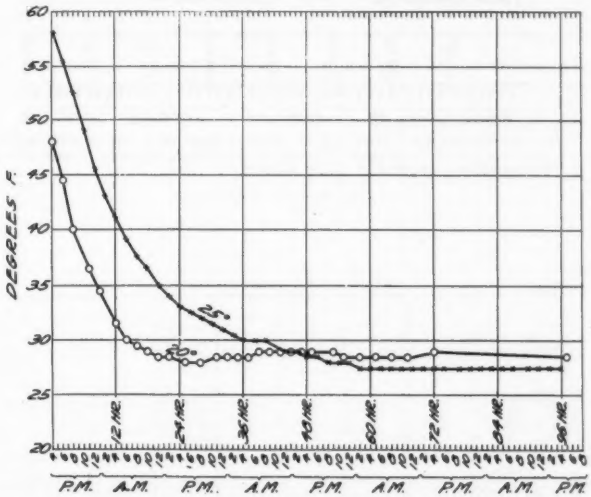


FIG. 10.—Comparison of the temperatures obtaining in the bottom of a barrel of unwrapped Winesap apples, during exposure to external temperatures around 25° F. for 96 hours with those obtaining in a barrel during exposure to temperatures at or below 20° F. for the same length of time

barrel exposed to 20° or below, while undercooling is definitely indicated in this case. The apples at the lower temperature began to freeze about 18 hours earlier.

The graphs showing the temperatures for the wrapped and unwrapped apples exposed to 20° F. or below are given in Figure 11, several facts being brought out in the curves. The much more rapid drop in temperature in the box of unwrapped apples is clearly defined, and both the top and bottom readings indicate that undercooling occurred, being particularly marked in the bottom. Consideration of the comparative differences existing between the readings for the top and bottom of the

At the close of the experiment the bottom temperature for the unwrapped apples was 3° lower than for the wrapped ones. That this has a practical bearing on the possible injury to the fruit will appear obvious in the light of other experiments in the temperatures at which freezing injury occurs and emphasizes the value of wrapping boxed fruit as a means of partial protection from low temperatures and resultant freezing.

Figure 12 compares the curves for the apple temperatures in the bottom of the barrel and in the lower part of the boxes. The comparative rates of the temperature drop in the barrel and box of wrapped apples clearly show

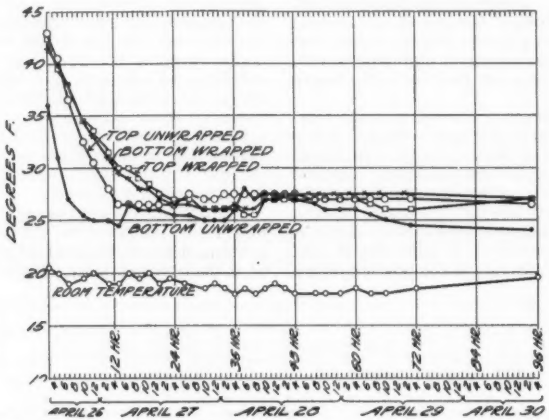


FIG. 11.—Temperatures obtaining in different parts of a box of wrapped and in a box of unwrapped Winesap apples, during exposure to external temperatures at or below 20° F. for 96 hours

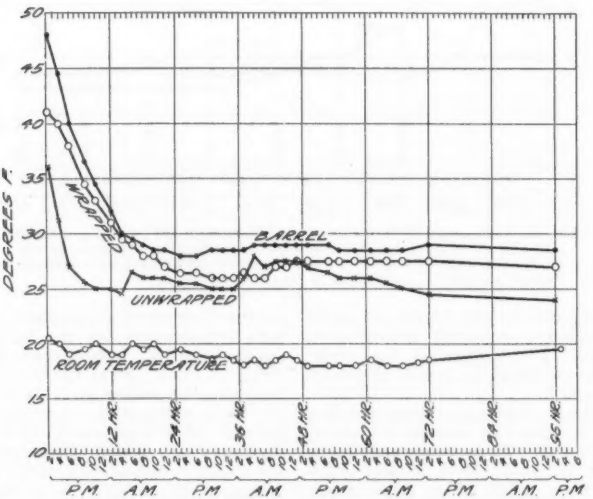


FIG. 12.—Comparison of the temperatures obtaining in the bottom of a box of wrapped, a box of unwrapped, and a barrel of unwrapped Winesap apples, during exposure to external temperatures at or below 20° F.

that the volume of fruit to be cooled tends to slow down the rate of cooling, and that wraps on the fruit produce a similar result. There is evidence that some of the fruit undercooled in both boxes and it is strikingly noticeable in the box of unwrapped fruit.

INJURY RESULTING FROM EXPOSURE OF APPLES IN PACKAGES TO FREEZING CONDITIONS FOR DIFFERENT PERIODS OF TIME

In addition to the lots described above in which the temperature change within the packages was observed, other lots were exposed to freezing conditions and removed at 24-hour intervals. After remaining at a temperature of 65° F. for 3 days the apples were examined for injury with the purpose of determining in 24-hour periods how long apples of different varieties in such packages could be exposed to certain freezing conditions without materially injuring the market value of the whole package.

Grimes Golden apples which had been in cold storage two weeks were exposed to temperatures from 19.5° F. to 21°, but about 20° most of the time. The fruit was packed in a 4 by 3 pack, 5 tiers high, in northwestern apple boxes with lids. York Imperial apples which had been in storage about three weeks were exposed to temperatures from 21° to 25°, but about 23° most of the time. Yellow Newtowns which had been in storage about five weeks were exposed to temperatures from 21° to 23.5°, but about 22° most of the time (Table IX).

The data shown in Table IX indicate that under prevailing conditions the Grimes Golden apples could hardly be exposed to a temperature of 20° F. for 48 hours without marked depreciation in market value. Undoubtedly 7.5 per cent of severe injury would be too high to be overlooked. The York Imperial apples showed only about 5 per cent severe injury after 48 hours, but the prevailing temperatures were somewhat higher. The Yellow Newtown showed about 5 per cent severe injury after a 72-hour exposure with a prevailing temperature slightly higher than that which obtained for the Grimes Golden, indicating that they were somewhat more resistant to freezing injury than the Grimes Golden.

The regular packing scheme used for each of these varieties permitted observations on the degree to which apples suffered visual freezing injury in different parts of the boxes. Apples in the interior lying in the second and third tiers from the top in any box seemed to be least affected by freezing conditions prevailing outside. Greater visual injury was found in apples touching the sides of the box, the corner apples being especially susceptible. If, however, the freezing conditions were severe as to either length or degree of exposure, the degree of visual injury found in the apples composing the lowest tier was generally so great throughout the tier that possible differences in injury intensity existing in apples at the side and at the center were not so apparent. The apples in the top tier in general showed somewhat more injury than the two immediately below it but considerably less than the two lowest tiers.

The varying power of resistance of different apples to conditions bringing about visual freezing injury was clearly demonstrated in these experiments. Specimens were found which showed very little injury after exposure to severe

TABLE IX.—*Percentage of visual injury in apples exposed for various periods of time at freezing temperatures and held at 65° F. for three days before inspection*

Average freezing-room temperature	Period of exposure	Percentage of visual injury			Total number of apples
		None	Trace	Severe	
	GRIMES GOLDEN FROM VIRGINIA				
20° F	24 hours	100.0	0	0	122
	48 hours	82.8	9.7	7.5	124
	72 hours	67.5	13.0	19.5	123
	YORK IMPERIAL FROM VIRGINIA				
23° F	48 hours	79.3	15.9	4.8	126
	72 hours	77.5	9.9	12.6	111
	96 hours	57.5	15.9	26.6	113
	YELLOW NEWTON FROM VIRGINIA				
22° F	48 hours	98.8	1.2	0	87
	72 hours	89.7	5.7	4.6	88
	96 hours	70.4	17.1	12.5	88
	120 hours	52.0	14.0	34.0	100

freezing conditions, though surrounded on all sides by severely injured apples. Tiers of fruit often contained apples showing a wide range in amount of injury present in their tissues.

EFFECT OF STORAGE FOLLOWING FREEZING UPON THE AMOUNT OF VISUAL INJURY IN APPLES

Four lots of apples, Yellow Newtown, Winesap, Rome Beauty, and Delicious, were exposed to somewhat similar freezing conditions at different times. They had been stored at 32° F. in commercial apple boxes previous to the experiments described here. Storage following the exposure to freezing conditions took place in the temperature averaging about 21°. After exposure for definite periods, one crate was removed to 65° where it was held three days, while another was placed in 32° for a month. Even after six days' exposure the damage was not very serious in apples stored in 65°, while of those put in 32° for a month, even those held at 21° eight days showed only a moderate amount of severe damage, although this would probably have increased materially if the fruit had been kept warm several days after removal from cold storage.

The Rome Beauty apples had been in 32° F. storage nearly three months when they were exposed in slat crates

TABLE X.—*Percentage of visual injury in apples exposed for varying lengths of time to freezing temperatures, and subsequently held at 65° F. for three days, or at 32° for a month before inspection*

Average freezing-room temperature	Period of exposure	Subsequent storage	Percentage of visual injury			Total number of apples
			None	Trace	Severe	
YELLOW NEWTOWN FROM VIRGINIA						
21° F.	24 hours	32° F.	100.0	0	0	100
	48 hours		100.0	0	0	100
	72 hours		100.0	0	0	100
	96 hours		60.3	15.9	23.8	126
WINESAP FROM VIRGINIA						
21° F.	48 hours	65° F.	87.3	9.3	3.4	118
	96 hours		97.9	2.1	0	136
	144 hours		86.5	8.5	5.0	141
	192 hours		39.7	30.7	29.6	166
	48 hours	32° F.	100.0	0	0	175
	96 hours		90.2	9.8	0	142
	144 hours		100.0	0	0	147
	192 hours		89.6	5.6	4.8	124
ROME BEAUTY FROM VIRGINIA						
22° F.	72 hours	65° F.	97.6	0	2.4	85
	96 hours		68.8	11.8	19.4	93
	144 hours		0	70.1	29.9	87
	192 hours		0	18.9	81.1	90
DELICIOUS FROM WASHINGTON						
22° F.	72 hours	65° F.	97.4	2.6	0	113
	120 hours		94.7	1.8	3.5	113
	168 hours		66.3	31.8	1.9	113

containers used during the exposure. The results obtained have been combined and are presented in Table X.

The Yellow Newtown apples, after five weeks in cold storage at 32° F., were exposed, in jumble pack in slat crates with no lid, to temperatures from 19° to 22.5°, but averaging 21°. After freezing, the fruit was held at a temperature of 32° for a month. The data given in Table X indicate that an exposure of 72 hours was not particularly damaging to the market value of the apples of this variety, but that 96 hours resulted in serious injury.

The Winesap apples, after about two months storage at 32° F., were exposed in slat crates without lids to a without lids to freezing room temperatures from 21.5° to 24° averaging about 22° most of the time. The subsequent storage was in 65° for three days. The data in Table X suggest that the apples suffered too severely after 72 hours' exposure to be in marketable condition in the original package.

The Delicious apples were exposed to the freezing temperatures in their original package but with wraps removed. The fruit had been in 32° F. storage about two months. The freezing-room temperatures ranged from 20.5° to 24°, averaging about 22° most of the time. Subsequent storage w a in 65° for three days. Mealiness be

comes very pronounced in this variety after a certain amount of freezing, but discoloration does not appear so commonly (Table X).

It will be noted that there is some variation in the amount of injury to different varieties when they are exposed for the same periods of time to freezing temperatures such as prevailed during the experiment. The small amount of visual injury found in Delicious apples, as a rule, is an example of this variation. Hence, the periods of time for which apples in packages may be exposed without serious depreciation in immediate market value will differ not only with the variety, but with the changing factors in packing, handling, and other conditions which we are not yet able to recognize.

In general, it may be said that for temperatures such as prevailed during these tests, which averaged between 21° and 22° F., the exposure period must not be over 72 hours if serious damage is to be prevented and 48 hours is a much safer figure for some varieties. The fruit here discussed was not wrapped. As shown below, wrapping may considerably extend the period during which fruit may be exposed to low temperature without injury.

TABLE XI.—*The effect of wrapping fruit on the amount of visual injury in Yellow Newtown and Delicious apples after exposure to freezing temperatures averaging 22° F. for various lengths of time*

Period of exposure	Wrapped or unwrapped	Percentage of visual injury			Total number of apples
		None	Trace	Severe	
YELLOW NEWTOWN FROM VIRGINIA					
72 hours	Unwrapped	89.7	5.7	4.6	88
72 hours	Wrapped	96.6	3.4	0	88
120 hours	Unwrapped	52.0	14.0	34.0	100
120 hours	Wrapped	88.4	4.2	7.4	95
168 hours	Unwrapped	29.5	14.7	55.8	95
168 hours	Wrapped	72.1	9.7	18.2	93
DELICIOUS FROM WASHINGTON					
72 hours	Unwrapped	97.4	2.6	0	113
120 hours	do	94.7	1.8	3.5	113
168 hours	do	66.3	31.8	1.9	113
208 hours	Wrapped	89.4	10.6	0	113
288 hours	do	60.3	35.2	4.5	113
360 hours	do	0	80.5	19.5	113

WRAPPING AS A RETARDANT OF FREEZING INJURY

Since it has been shown that wrapping materially retards the cooling in the fruit (see above, p. 110 to 111), it could be expected to reduce the amount of visual injury. Data are given in Table XI on the effect of exposing wrapped Yellow Newtown apples, packed in northwestern apple boxes, 4–3 packs, 5 tiers high, to temperatures from 21° to 23.5° F. for different lengths of time. Data are also given for Delicious apples, exposed in boxes as originally packed, to freezing-room temperatures from 20.5° to 24°, averaging 22° most of the time. Wrappers were removed from the latter apples in some boxes, but this packing arrangement was not otherwise disturbed. After exposure to these temperatures for the required time both groups of apples were held at 65° for three days before examination.

A comparison of results with wrapped and unwrapped lots, shown in Table XI, indicates that wrapping markedly retards visual injury. For instance, the percentage of injury for unwrapped Delicious apples exposed five days is not radically different from that for wrapped apples exposed nine days. There is a similar difference if 7-day wrapped fruit is compared with 12-day unwrapped fruit. These observations apply only to the amount of visual injury developed.

Wrapping apples not only retards visual injury, but has other beneficial effects during thawing. It retards the rapid water loss which often takes place in the fruits, especially when thawing occurs at comparatively low humidities, and also lowers the amount of injury due to bruising while hard frozen, the latter feature being important if the fruit is hard frozen while in transit and subjected to jolting and jarring.

EFFECT OF WILTING ON FREEZING INJURY

Two collateral lots of Grimes Golden apples were picked early in the season, and one lot was subjected to freezing temperatures after only a short storage period at 32° F. The other lot was held in slat crates in storage at 32°

nearly four months before exposure to freezing conditions. The apples in this lot were badly wilted. Both lots were subjected to freezing temperatures which were never above 22.5° and were mostly about 21°.

That wilting retarded visual injury when apples were frozen is evident, especially in those lots exposed for the longer periods of time (Table XII).

THE EFFECT OF REPEATED FREEZING AND THAWING UPON THE FREEZING POINT AND AMOUNT OF VISUAL FREEZING INJURY

In order to study the effect of repeated freezing and thawing on freezing points of apples, also upon the amount of visual injury which results, thermocouples were used to obtain the internal temperatures, and when the apples had started to freeze they were removed and thawed by placing in a warm room over night. Each apple was then replaced on the thermocouple which had been used to read the first freezing point and another determination made. In this way the same thermocouple was used for all readings on any one apple.

The first of the series of experiments was made up of 24 Rome Beauty apples thawed at 70° F. after freezing. For the first time, the average freezing point was 28.8°, for which the freezing room temperature ranged from 21.7° to 22°. The second freezing on the same apples gave an average freezing point of 29.5° with a similar room temperature, the raising of the freezing point amounting to 0.8°. Another experiment with 23 Rome Beauty apples with freezing-room temperature from 21.7° to 22° as before, but for which the thawing temperature was 50°, gave 29.4° for the first and 29.6° for the second average freezing point. Five Delicious apples, with temperature near 22°, showed the first average freezing point to be 29.2°, the second 29.4°. Ten Yellow Newtown apples, frozen three times with temperature near 22°, showed the first average 28.3°, the second 28.7°, the third 28.7°. These figures indicate that the freezing points of apples are slightly higher after they are once frozen.

Rome Beauty apples in slat crates without lids were used in the experiments to determine the effect of repeated freezing and thawing on visual injury. The room temperature was between 21° F. and 22° most of the time, with a few intervals at 20°. The crates were held at 65° for three days between the intermittent freezing periods of 72 hours and those of 96 hours, and this was also true at the end of the periods of continuous exposures (Table XIII).

Apparently there is an increase in the amount of injury with each successive exposure to freezing conditions. As noted above, the freezing point is apparently higher with successive freezing and thawing, and it is probable that successive exposures to freezing conditions result in a greater total quantity of ice formed in the tissue with successive freezings following thawing. Comparison of the repeatedly frozen lots with those continually exposed to like low temperatures for similar periods shows that freezing injury is much more severe following 144 hours continuous exposure than following two exposures of 72 hours each, with thawing between. This again is probably associated with the amount of ice formed in the tissues, for the internal temperature of the fruit would more nearly approach the air temperature during a single long exposure than during two exposures of equal total length, but with an interval of high temperature between.

TABLE XII.—*Effect of wilting upon visual injury in Grimes Golden apples after freezing at temperatures averaging 21° F.*

Period of exposure	Condition of fruit	Percentage of visual injury			Total number of apples
		None	Trace	Severe	
48 hours	Unwilted	82.8	9.7	7.5	124
	Wilted	94.5	4.7	.8	127
72 hours	Unwilted	67.5	13.0	19.5	123
	Wilted	90.9	8.3	.8	133
96 hours	Unwilted	66.7	14.3	19.0	126
	Wilted	78.8	18.3	2.9	137
120 hours	Unwilted	32.5	23.0	44.5	126
	Wilted	67.5	20.5	12.0	125

TABLE XIII.—*Effect of repeated freezing at temperatures about 21° F. and of repeated thawing upon the amount of visual injury in Rome Beauty apples*

Number of times exposed	Period of each exposure	Percentage of visual injury			Total number of apples
		None	Trace	Severe	
	COMPARISON OF SUCCESSIVE INTERMITTENT PERIODS				
1	72 hours	97.6	0	2.4	85
2	72 hours	88.4	3.5	8.1	86
3	72 hours	0	88.7	11.3	71
1	96 hours	68.8	11.8	19.4	85
2	96 hours	0	56.5	43.5	85
3	96 hours	0	64.5	35.5	93
	COMPARISON OF INTERMITTENT PERIODS WITH CONTINUOUS EXPOSURE OF SAME HOUR TOTAL				
2	72 hours	88.4	3.5	8.1	86
1	144 hours	0	70.1	29.9	87
3	72 hours	0	88.7	11.3	71
1	216 hours	0	12.6	87.4	95
2	96 hours	0	56.5	43.5	85
1	192 hours	0	18.9	81.1	90
3	96 hours	0	64.5	35.5	93
1	288 hours	0	0	100.0	93

CHANGE IN THE FREEZING POINT OF APPLES HELD IN COLD STORAGE

The opinion has been expressed that the freezing point of apples held in cold storage is higher during the latter part of the storage period than at the time of placing in storage, and that at the end of the season the apples are more susceptible to visual freezing injury. While this injury in frozen fruit is more common as the storage season progresses, work with two varieties held at 32° F. throughout the season does not confirm the view that the freezing point thus rises. After apples are picked and placed in storage the tissue undergoes progressive physiological changes which eventually lead to maturity and overripeness, and possibly render the apple less resistant to freezing temperatures. This may account for the apparent greater visual injury in apples frozen toward the end of the storage season with the freezing point quite constant throughout. These physiological changes are also indicated by the more rapid development of mealiness under freezing conditions late in the storage season. But a progressive and sustained raising of the freezing point is not indicated (Table XIV).

TABLE XIV.—*Freezing points of Rome Beauty and Ben Davis apples held continuously in a temperature of 32° F. and tested at intervals of about a month through the storage season*

Date of test	Freezing point			Freezing-room temperature range		Number of apples used
	Average	Maximum	Minimum	Maximum	Minimum	
	ROME BEAUTY FROM VIRGINIA					
	°F.	°F.	°F.	°F.	°F.	
Nov. 2	29.1	29.8	28.4	21.4	21.1	42
Dec. 9	29.3	29.9	28.4	22.2	21.8	46
Jan. 10	29.3	29.8	28.6	23.4	23.2	47
Feb. 10	29.4	30.1	28.5	22.0	21.7	47
Mar. 13	29.1	29.9	28.7	23.5	23.1	21
	BEN DAVIS FROM VIRGINIA					
Nov. 7	29.0	29.4	28.7	22.2	20.3	24
Dec. 18	28.8	29.2	28.2	22.4	21.9	45
Jan. 15	29.0	29.5	28.3	22.2	21.9	42
Feb. 14	29.0	29.5	28.6	22.7	21.8	34
Mar. 13	29.0	29.5	28.4	23.5	23.1	23

EFFECT OF DIFFERENT THAWING TEMPERATURES ON FROZEN APPLES

Shippers and handlers of apples generally believe that frozen apples are injured less by gradual thawing, or storage at low temperatures, after freezing, than by rapid thawing at high temperatures. While evidence on this question is not altogether clear, the data in Table X indicate that somewhat more severe injury occurred in fruit thawed at 65° than in fruit thawed at 32°. Very rapid thawing

by immersing in warm water has been found to result in more severe injury than thawing even in 65° air. Consequently, thawing of commercially frozen fruit at moderately low temperatures is to be recommended. Aside from the question of actual freezing injury, the breakdown following freezing will go on much more rapidly at high temperatures. Unless the fruit is so severely frozen as to be unmarketable, handling at as low a temperature as possible will give most satisfactory results. But holding at low temperatures will not result in the recovery of apples so severely frozen as to be seriously discolored inside. Sudden transfer of frozen fruit to warm dry conditions may cause wilting, as the water resulting from melting ice crystals in the intercellular spaces of the tissue may not be reabsorbed by the cells if the thawing process is such as to induce a rapid exchange of water vapor to the outer air.

TABLE XV.—*Effect of freezing at temperatures from 20° F. to 21.5° on the softening of Yellow Newtown apples, as measured by the pressure tester, and on acidity and amount of visual injury found*

Period of exposure to freezing temperature	Period and temperature subsequent storage	Pressure in pounds necessary for puncture		Percentage acidity as malic acid	Number of apples showing visual injury		
		Pared	Unpared		None	Trace	Severe
None	None	16.5	22.3	0.653			
Do	24 hours at 65° F	15.6	22.0	.709			
7 hours	do	16.4	22.4	.695	16	6	3
17 hours	do	15.1	20.9	.599	11	6	8
24 hours	do	14.2	20.2		15	7	3
31 hours	do	14.1	21.6	.618	11	5	9
48 hours	do	13.5	19.3	.627	3	6	16
72 hours	do	12.0	19.7	.589	1	6	17
None	1 month at 32° F	15.4	22.8	.592			
7 hours	do	14.2	20.9		18	2	0
17 hours	do	14.0	19.6	.546	16	4	1
24 hours	do	13.1	19.6		16	2	2
31 hours	do	13.6	19.7	.563	14	5	1
48 hours	do	12.4	18.4	.545	10	8	2
72 hours	do	11.8	18.7		5	4	11

EFFECT OF FREEZING AS DETERMINED BY THE PRESSURE-TEST METHOD AND BY ACIDITY DETERMINATIONS

The work on visual freezing injury indicates an increase in severity and extent of injury as apples are subjected to progressively longer periods of exposure. To determine whether there is also a progressive change not evident to inspection by the usual method, experiments were carried out with a few varieties exposed to low temperatures for different periods of time. In addition to examination for visual injury the fruit was tested for softness by pressure according to the method already described; and acidity determinations were made on samples of apple tissue. These samples were obtained by cutting out plugs of tissue with a cork borer and pulverizing by passing through a sampling press of the type described by Clark (*2*); 100 gm. of tissue were weighed out, boiled, and made up to 1,000 cc. with distilled water. The samples were preserved with toluol, and after extraction for three days were filtered and titrated with phenolphthalein as indicator. The results are expressed in percentage of the wet weight of the tissues, the acid being calculated as malic.

In other experiments Yellow Newtown apples which had been held in storage at 32° F. about five months were subjected to temperatures from 20° to 21.5°. The fruit was exposed without packing or wrapping, arranged on a wooden platform so that each apple was several inches away from surrounding apples. At invervals sample lots of 20 to 24 apples were removed, one lot being placed in a temperature of 65° for 24 hours, the other in cold storage at 32° for one month, after which these lots were compared with unfrozen apples from the same general storage. Both the frozen and unfrozen fruit taken from the 32° storage were tested immediately (Table XV).

Ice had formed in the majority of the apples at the 17-hour period, and at all periods longer than 17 hours it may be assumed that the freezing process was adding to the amount of ice first formed. The data for the pressure tests show some variation especially in the column in which unpared apples are considered, but the figures for tests with pared apples seem to describe more accurately the condition of the interior tissue of the fruit, because tests with unpared

fruit necessarily include the resistance of the skin to rupture, which may possibly not be affected even in severe cases of freezing injury.

The data indicate a progressive softening in apples that have been frozen for increasingly longer periods of time, both when they were tested after 24 hours and when they had been in cold storage a month. Comparison of the pressure tests and the amount of visual injury show that appreciable softening can be detected at periods when visual injury is quite negligible in any particular lot. This indicates that apples are actually softened by the ice formation incident to freezing, and are softer and more mealy following thawing, even though no visual injury has occurred. This means that frozen apples are nearer to the end of their storage life. They can not be held so long as unfrozen fruit and be in good condition for merchandising after removal from storage.

The acidity changes show a distinct but irregular decrease with freezing in the case of the Yellow Newtown apples. This irregularity may be due to variations in the samples, for distinct variations occur even in unfrozen lots.

Another experiment was carried out with Ben Davis apples which had been held about five months in 32° F. They were subjected to freezing temperatures at about 22° for different periods of time. The procedure was the same as that employed in the experiments with Yellow Newtown apples discussed above, except that at each removal hour one sample lot was placed in 65° for a week (Table XVI).

The data are similar in character to those obtained for the Yellow Newtown apples, and show that as the periods during which the apples are frozen and held at freezing temperatures are lengthened, the fruit is softer upon thawing. It probably is also true that softening during subsequent storage is hastened by the freezing injury. It is noticeable that the visual injury and the pressure-test figures do not show increases of similar degree, and that softening occurs when visual injury is not present. The increase in acidity noted during storage is probably only apparent, and may result from a loss of water from the tissues, since the acidity is calculated to the wet weight of the tissues.

TABLE XVI.—*Effect of freezing at temperatures around 22° F. on the softening of Ben Davis apples in lots of 20, as measured by the pressure tester, and on acidity and amount of visual injury found*

Period of exposure to freezing temperatures	Period and temperature of subsequent storage	Pressure in pounds necessary for puncture		Percentage acidity as malic acid	Number of apples showing visual injury		
		Pared	Unpared		None	Trace	Severe
None	None	12.1	15.6	0.412			
Do	24 hours at 65° F	12.4	17.4	.396			
8 hours	do	11.1	15.5	.425	16	2	0
16 hours	do	11.5	15.5	.435	16	3	1
24 hours	do	9.7	13.7	.411	17	3	0
32 hours	do	11.1	14.6	.433	20	0	0
41 hours	do	10.7	14.6	.436	20	0	0
48 hours	do	10.7	15.3	.448	16	4	0
None	1 week at 65°	11.0	16.3	.349			
8 hours	do	11.1	15.4	.450	20	0	0
16 hours	do	10.8	14.3	.397	14	4	2
24 hours	do	10.7	14.6	.406	13	2	5
32 hours	do	10.3	14.0	.418	16	1	3
41 hours	do	9.8	13.7	.421	16	1	3
48 hours	do	8.5	12.6		10	3	7
None	1 month at 32°	10.5	15.3	.308			
8 hours	do	10.7	14.5	.407	20	0	0
16 hours	do	10.5	12.9	.377	14	3	3
24 hours	do	10.0	13.5	.375	12	3	4
32 hours	do	9.8	12.9	.356	16	0	4
41 hours	do	9.6	13.3		11	1	7
48 hours	do	9.1	11.7	.378	14	2	4

The above experiments were carried on at temperatures distinctly below the freezing points of the fruit used. In order to determine whether changes occur at temperatures just below the freezing point, tests were made on Winesap and Yellow Newtown apples grown in Virginia which had previously been in storage at 32° F. nearly six months. The two varieties were tested at the same time, with the freezing room held at temperatures ranging from 27° to 28°, except for a short period of 26° at the beginning. Fruit thermometers were inserted in scattered apples when they

were exposed to the low temperatures and were read every 24 hours. In this way an estimate of the temperature conditions in the whole lot was obtained. While this practice is not so satisfactory as readings at shorter intervals, the temperature changes in frozen apples while ice is being formed are rather slow at the freezing room temperatures used, so the method proved satisfactory (Table XVII).

of a thoroughly frozen apple. The acidity in a few instances shows a decrease from that found in unfrozen apples, but it is slight and irregular, and not significant.

Since the differences noted above are small, although distinct enough so that they seem noteworthy, another series of experiments was made on apples subjected to temperatures which remained between 26° F. and 26.5°.

TABLE XVIII.—*Effect of freezing, at a temperature just below their freezing point, on the softening of Winesap and Yellow Newtown apples, as measured by the pressure tester, and on the acidity and amount of visual injury found*

Periods of exposure to freezing temperatures	Period and temperature of subsequent storage	Pressure in pounds necessary for puncture		Percentage acidity as malic acid
		Pared	Unpared	
	WINESAP			
None	None	13.9	19.0	0.560
Do	24 hours at 65° F.	13.2	17.6	.528
24 hours	do	13.6	18.5	.548
48 hours	do	12.8	17.4	.550
72 hours	do	13.1	16.9	.557
None	2½ weeks at 32°	13.6	17.7	.529
24 hours	do	13.2	17.2	
48 hours	do	12.6	17.5	.517
72 hours	do	12.7	17.6	.550
	YELLOW NEWTOWN			
None	None	16.2	23.4	0.570
Do	24 hours at 65°	15.7	22.3	.514
24 hours	do	15.9	23.6	.519
48 hours	do	14.8	22.6	.543
72 hours	do	14.4	21.3	.558
None	2½ weeks at 32°	13.8	21.6	.526
24 hours	do	13.6	21.2	
48 hours	do	13.2	21.0	.499
72 hours	do	13.6	21.3	.513

The average freezing point of the Winesap apples used in this experiment was 28° F. and of the Yellow Newtown apples 28.8°. The readings at the 72-hour period indicate that the apples were still at their freezing point at that time, or very near it, as they probably were also at the 48-hour period, though the amount of ice in the tissue had undoubtedly increased. Table XVIII presents the pressure test and acidity figures for sample lots of these apples withdrawn at 24-hour intervals when the temperatures were read. The storage and testing procedure was similar to that used in other experiments of the same general character. No visual injury was detected.

As in the experiments conducted at temperatures around 22° F., there is indication that the softening of apples is hastened by freezing. Although the differences are slight, the amount of ice formed in the apples held at a temperature just below the freezing point may be small, and none of the fruit was in the hard wrinkled condition

Five Virginia varieties, which had been held at 32° F. about seven months, were used. Acidity determinations were made only for the first

TABLE XVII.—*Internal temperatures of 5 Winesap and 5 Yellow Newtown apples exposed to a temperature just below their freezing point for different lengths of time*

Apple No.	24-hour period	48-hou period	72-hour period
	WINESAP		
	°F.	°F.	°F.
1	29.0	28.5	28.0
2	29.0	28.5	28.0
3	28.5	28.5	28.0
4	28.5	28.0	28.0
5	29.0	28.0	28.0
	YELLOW NEWTOWN		
1	29.5	28.5	28.5
2	29.0	29.0	28.5
3	29.0	29.0	29.0
4	29.5	29.5	28.5
5	29.0	29.5	28.0

two, and the procedure of the experiment was similar to that of those already described, with subsequent storage at 32° for two and one-half weeks for Winesap and Yellow Newtown (Table XIX).

TABLE XIX.—*Internal temperatures of certain Winesap, Yellow Newtown, Rhode Island Greening, Ben Davis, and Rome Beauty apples while exposed to temperatures between 25° F. and 26° for different lengths time* [a]

Apple No.	Internal temperatures of the fruit and length of period		
	24-hour period	48-hour period	72-hour period
	WINESAP		
	° F.	° F.	° F.
1	27.0	28.0	27.5
2	26.5	27.5	27.0
3	25.0	26.5	26.5
	YELLOW NEWTOWN		
1	27.0	26.0	28.5
2	28.5	28.0	27.5
3	27.0	26.5	27.5
	RHODE ISLAND GREENING		
1	29.0	27.5	27.0
2	26.5	28.0	27.0
	BEN DAVIS		
1	29.0	27.0	27.0
2	29.0	27.0	27.0
	ROME BEAUTY		
1	27.5	28.5	28.0
2	27.0	29.0	27.5

[a] Average freezing points of the varieties used were: Winesap, 28°; Yellow Newtown, 28.8°; Rhode Island Greening, 28.8°; Ben Davis, 28.9°; Rome Beauty, 29°.

The temperatures indicated that ice formation had taken place in many apples at the 24-hour period; and the hard-frozen condition of the fruit at the 48-hour period showed that it had proceeded to a considerable extent in all of the fruit. A drop in the apple temperatures would indicate that the major portion of the ice possible in the tissue at that temperature had formed, and that the fruit was losing heat more rapidly to the environment than it was gaining from the heat of fusion as new amounts of ice were formed.

As has been observed in apples frozen at temperatures considerably below and just below their freezing point, the fruit of the five varieties subjected to temperatures near 26° F. showed a progressive softening as the time of exposure increased. In some varieties this is more noticeable than in others, due not to varietal peculiarities alone, but also to such conditions as differences in the size of the apples, the water content of the fruit, and their effect on the degree of ice formation.

TABLE XX.—*Effect of freezing apples at temperatures between 25° F. and 26° upon softening as measured by pressure tester*

Period of exposure to freezing temperatures	Period and temperature of subsequent storage	Pressure in pounds necessary for puncture	
		Pared	Unpared
	WINESAP		
None	None	13.5	16.7
Do	24 hours at 70° F.	13.0	17.2
24 hours	do	12.6	15.8
48 hours	do	12.6	16.3
72 hours	do	11.9	15.2
None	2½ weeks at 32°	12.7	16.2
24 hours	do	12.1	16.3
48 hours	do	12.4	15.4
72 hours	do	12.4	14.8
	YELLOW NEWTOWN		
None	None	14.3	21.7
Do	24 hours at 70°	14.1	21.4
24 hours	do	12.9	20.5
48 hours	do	12.9	19.9
72 hours	do	11.4	18.6
None	2½ weeks at 32°	13.7	20.6
24 hours	do	13.8	19.8
48 hours	do	12.5	19.0
72 hours	do	12.0	18.7
	RHODE ISLAND GREENING		
None	None	11.7	13.9
Do	24 hours at 70°	11.7	13.8
24 hours	do	10.0	12.6
48 hours	do	9.6	12.0
72 hours	do	9.0	11.4
	BEN DAVIS		
None	None	15.1	19.9
Do	24 hours at 70°	15.0	18.8
24 hours	do	13.9	18.5
48 hours	do	13.1	17.6
72 hours	do	13.3	17.6
	ROME BEAUTY		
None	None	12.4	15.9
Do	24 hours at 70°	11.1	15.4
24 hours	do	11.4	14.8
48 hours	do	11.7	15.6
72 hours	do	10.9	14.5

The acidity changes are not given in table form, since they were not significantly different and resemble those for earlier freezing tests. The majority of cases exhibited no visual injury whatever, though a few showed a slight trace.

SUMMARY AND CONCLUSIONS

1. Freezing-point temperatures of a considerable number of important commercial varieties of apples have been determined. The average freezing point of all the varieties, both eastern and western grown, was 28.5° F., the maximum 29.4°, the minimum 27.8°.

2. Cooling apples below their freezing points without the formation of ice in the tissue does not cause any visual injury or perceptible softening of the fruit.

3. Undercooling of isolated apples can sometimes be carried to a point as low as 7 or 8 degrees below their freezing point without ice formation, provided the fruit is left undisturbed.

4. Inoculation or the beginning of ice formation in apples takes place rather slowly at times, and ice formation in the tissues does not spread so rapidly as in some other plant organisms that have been studied.

5. The bruising of apples while they are hard frozen results in a much more serious injury than does a similar pressure on unfrozen fruit. Consequently, any handling of frozen apples will usually result in more or less severe bruising injury.

6. The severity of the injury caused by bruising frozen apples is lessened as the amount of ice in the tissues decreases during thawing.

7. Bruises made on apples before they are frozen do not become more serious as to depth when the fruit is frozen, nor do they change materially in appearance.

8. There are no significant differences in the depth of bruises on hard-frozen fruit when subjected to different thawing temperatures.

9. Visual freezing injury may be classed under two heads, that appearing in the tissues of the apple, and that appearing on the surface, both being found in the same apple or occurring independently.

10. Visual freezing injury exhibits a great variety of forms and intensities which depend not only on the severity and duration of the prevailing freezing temperatures, but also on other factors, such as the physiological condition of the fruit.

11. The point to which the internal temperature of an apple must be reduced before visual injury occurs varies widely with the time of exposure to the temperature, with the variety, and with the individual apple. Under conditions of moderate thawing rates and rather short exposures to freezing conditions, it was found that the interiors of the apples usually had to reach a point at least 2° to 3° below the actual freezing temperatures after ice formation had started, before visual injury occurred. As the internal temperature dropped lower there was a rapid increase in the amount and severity of the injury, due probably to the increase in the quantity of ice formed in the fruit.

12. The data on the rate of cooling down of different packages at different freezing temperatures emphasize that apples can be exposed in such packages for considerable periods of time without the occurrence of any considerable actual freezing. There is some evidence that apples scattered through different parts of the package do freeze and that the heat produced by the ice crystallization in their tissues raises the temperature of the mass of fruit as a whole sufficiently to delay freezing in it. It does not seem possible to carry the undercooling of apples in packages to the degree to which it has been shown to occur in isolated, undisturbed apples, surrounded on all sides by cold air.

13. The fruit in the lower part of a package held under freezing conditions is exposed to a greater danger of freezing injury than that in any other portion of the package.

14. Wrapping serves to hinder the loss of heat from fruit under freezing conditions, thereby delaying the formation of ice in the fruit tissues. In this way the amount and severity of the freezing injury may be reduced, as regards both that determined visually and by means of other tests.

15. Repeated freezing and thawing of apples causes a progressive increase in the freezing injury, though not so great an increase as a prolonged continuous exposure. Thus two exposures of 90 hours each to freezing conditions will cause more injury than one exposure of 90 hours, but less than one exposure of 180 hours.

16. There is no evidence of progressive and sustained raising of the freezing point of apples held in 32° F. during the storage season. The greater susceptibility of apples to freezing injury as the storage season progresses lies apparently in a change in the physiological condition of the fruit and is not determined by a changing freezing point.

17. The temperatures at which apples are ordinarily thawed have only a slight effect upon the subsequent condition of the fruit. Yet very high temperatures and low humidities are not recommended because of the rapid water loss from the fruit under such conditions and the more rapid development of other injurious effects.

18. There is a distinct weakening in the keeping quality of apples when they are frozen, even when there is no visual evidence that freezing has occurred. The tissues of frozen apples are softer and more mealy after thawing and in poorer condition to stand storage and marketing, even though no direct discoloration has occurred. The degree of this softening again varies with the exposure and intensity of the freezing period.

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OILED PAPER AND OTHER OILED MATERIALS IN THE CONTROL OF SCALD ON BARREL APPLES[1]

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INTRODUCTION

Scald is one of the serious storage and market diseases of apples, and is particularly bad on the fruit that is stored in barrels. The barrel package is a tight one and its bulk of fruit relatively large, with the result that the apples cool more slowly than those in smaller and more open packages and also have less opportunity for the elimination of moisture, odors, or other waste products. In addition to this, a number of the varieties that are usually packed in barrels are naturally susceptible to scald and several of them are largely grown in the more southern orchard sections where picking and packing often begin while the weather is warm. These various conditions have made scald a particularly serious problem in the storage of barrel apples. The present paper gives a report of experiments in the use of oiled paper and other oiled materials for the control of scald in the barrel package.

HISTORICAL

Investigations looking to the control of apple scald extend over the last quarter of a century. They have developed a number of methods of reducing the disease and several of these have been put into practice to an extent to be of material value to the apple industry.

The first definite contribution in the study of scald was made in 1903 by Powell and Fulton (*16*).[2] They found that mature fruit scalded less than immature, and well-colored apples less than poorly colored ones, that less scald developed at a storage temperature of 31° to 32° F. than at a temperature of 36° F. or higher, and that delays in reaching storage were extremely favorable to the development of the disease.

Following this pioneer investigation no extended study of scald was made for a number of years. In 1904 (*4*) and again in 1909 (*5*) Beach published notes supporting the results of Powell and Fulton and in 1913 Greene (*12*) reported further supporting evidence. Greene found, however, that apples often scalded less in good cellar storage than in cold storage and that apples that were delayed in reaching storage sometimes scalded less than those that were stored immediately.

Ramsey, McKay, Markell, and Bird (*19*) in 1917 obtained results on the northwestern box apples similar to those of Powell and Fulton on the eastern barrel apples. Their investigations covered a period of four years and their experimental data gave conclusive proof that bad scald could be greatly decreased by picking the fruit at proper maturity. Apples that were delayed two weeks in reaching storage usually developed considerably more scald than those that were stored immediately and less scald developed in 32° F. storage than in 35° F. storage. They made withdrawals from storage at intervals of four to six weeks and reported data showing the progressive development of scald during the storage period.

Brooks and Cooley (*6*) (1917) and Brooks, Cooley, and Fisher (*7*) (*8*) (*9*) (*10*) (1919), (1923) found that immature apples scalded much worse than mature ones but that the mature ones might scald earlier in the storage season than the immature ones. Apples from heavily irrigated trees scalded worse than those from trees receiving more moderate irrigation. The rate of development of scald increased with a rise in temperature up to 15° or 20° C. (59° or 68° F.) but no scald occurred at 25° or 30° C. (77° or 86° F.). Scald was not due to the shock from the change of temperature on bringing the apples out of storage, but largely to the conditions that prevailed during storage. Delayed storage without ventilation resulted in increased scald but

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[2] Reference is made by number (italic) to "Literature cited," pp. 134–135.

delayed storage with free air movement over the apples served as a partial preventive for storage scald. Apples scalded less in boxes, baskets, hampers, and ventilated barrels than in the usual tight barrels. Increasing or decreasing the oxygen content of the storage air had little or no effect upon scald; increasing the carbon dioxide content tended to decrease scald. Excessive humidity favored the development of scald but was not usually an important determining factor in its development. Injuries apparently identical with scald could be produced by exposing apples to the vapors of esters and other substances that were constituents of the odorous products of the apple. Scald was reduced by coating the apples with a thin film of oil but the appearance of the fruit was often injured by the treatment. Oiled blotter material scattered through the package reduced the scald without injury to the fruit. Packing the apples in oiled wrappers (carrying 15 per cent or more of their weight in oil) was found to be the most satisfactory and efficient method of controlling scald. Ordinary unoiled wrappers were of little or no value in scald-control and paraffin wrappers far less efficient than the oiled ones. The value of the various oil treatments in scald-control was thought to depend largely upon the ability of the oils to absorb the odorous substances thrown off by the apples. The conditions leading up to scald were found to be of a cumulative nature, subject to remedial measures during the first six or eight weeks of storage but after that time often beyond remedy.

Power and Chesnut (*17*) (1920) found that the odorous constituents of apples consisted essentially of the amyl esters of formic, acetic, and caproic acids, with a very small amount of the caprylic ester and a considerable proportion of acetaldehyde. In a later publication (*18*) (1922) geraniol was added to the list of odorous constituents.

Whitehouse (*20*) (1919) stored Iowa apples under different humidities and found that slightly more scald developed with a relative humidity of 80 to 90 than with a relative humidity of 60 to 70. The degree of temperature had a much greater influence in the development of scald than the degree of humidity, a constant temperature of 32° F. giving the best results. Wrapping apples delayed the appearance of scald and paraffin paper retarded the disease slightly more than the ordinary wrapper.

A later report (*11*) (1922) from Iowa Agricultural Experiment Station stated that the use of oiled wrappers practically controlled scald in all cases tested.

Magness and Burroughs (*13*) (1922) pointed out the relation of wilting to scald resistance. They obtained more scald with apples exposed to a high humidity than with those exposed to a lower humidity, and were of the opinion that the effect of ventilation or air circulation in reducing scald might be mainly an action of drying of the surface of the fruit.

Marble (*14*) (*15*) (1922), (1923) also emphasized the relation of wilting to scald resistance. He thought that low temperatures had a depressing effect on apples and lessened the resistance of certain varieties to scald. Ventilation was effective in preventing scald if the temperature was high enough for the variety.

Adam (*1*) (1923) reported that Australian apples scalded more when immature than when mature. He found in agreement with others that scald was worse the higher the temperature, and that efficient ventilation practically eliminated the disease.

Baker (*2*) (*3*) (1924) reported results confirming the efficiency of the oiled wrappers in scald control. In an experiment on Grimes apples he found that shredded paper gave practically as good scald control as the wrappers.

EXPERIMENTAL RESULTS

The commercial results of the past two years seem to indicate that the oiled wrapper has largely solved the scald problem so far as box apples are concerned but it does not meet the requirements of the barrel packer. Experiments extending over a period of six years have proved that the oiled wrappers will largely control scald as it occurs in the barrel package and some growers have found it profitable to pack their apples in this manner, but the difficulty of placing wrapped apples in barrels and the cost of the operation make the oiled wrapper impracticable so far as the general barrel trade is concerned. The situation has created an increased demand for a method of scald-control adapted to the barrel package. The first method that suggested itself for controlling scald apart from the wrapper was that of applying the oil directly to the skin of the apples. A large number of tests of this sort were made and various mixtures of oils and waxes were tested. The results (*10*) were not satisfactory. In nearly

all cases the oils and waxes reduced the scald and in some instances almost entirely controlled the disease, but the apples had a greasy appearance upon removal from storage, the natural bloom was lacking, the skin was often abnormally green and in some cases it was definitely injured, turning brown much as if affected with scald.

Incidental results in various oiled wrapper experiments indicated that it ought to be possible to control scald without coating the skin with oil or actually inclosing the apple in a wrapper. In many of the oiled wrapper experiments only a part of the apples of the package were wrapped and this gave a chance to note the effect of the wrapper upon the adjacent unwrapped fruit. It was found that scald on the immediately adjacent apples was reduced to about one-fourth of that on the control barrels and that the scald on apples two or more layers distant from the oiled wrappers was reduced to about 60 per cent of that on the control. The results led to efforts to carry the oil of the package by other means than the wrapper or the direct application to the skin of the apple.

OILED BARRELS AND OILED LINERS

An experiment was made in which the barrels were soaked in oil. Approximately one pound of mineral oil was applied to the inner surface of each barrel and was absorbed by the wood. The effect that this treatment had upon the development of scald on Grimes Golden apples is shown in Table I.

Experiments were also made in lining the barrels with a double layer of ordinary desk blotters which had been saturated with oil. Approximately one pound of oil was used in each barrel. The tests were carried out on Grimes Golden, York Imperial, and Arkansas (Mammoth Black Twig). The results are shown in Table I.

The oiled barrels reduced the scald on the outside apples but had practically no effect upon those in the center of the barrel. The oiled liners gave similar results on the adjacent fruit and in some instances seemed to reduce scald upon the apples that were at a distance of several layers. Neither of the treatments was considered a practical success.

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OILED LAYERS

The effect of layers of oiled paper was also tested. A single layer of apples was placed in the barrel, then a layer of oiled wrappers, followed by another layer of apples, and this in turn by a layer of oiled wrappers. As many wrappers were used in a layer or paper as there were apples in the layer of fruit immediately beneath, thus making the quantity of paper in the barrel the same as if the apples had been wrapped and giving each apple two areas of contact with the wrappers. The experiment was carried out on two separate lots of York Imperial apples and the results are shown in Table II. The layers of oiled paper gave almost as good scald control as was obtained on the apples that were wrapped individually in similar paper.

As a commercial proposition there would obviously be an advantage in having circles of paper the size of the barrel rather than the wrappers but the above method furnished a means of testing whether a given amount of paper would have the same efficiency in scald-control when placed in layers between the apples as it would have if wrapped around the apples. The results seem to indicate that the actual inclosing of the apple in the wrapper is not a matter of extreme importance, at least for barrel fruit.

OILED BLOTTER STRIPS

Experiments were made in which ordinary desk blotters were heavily oiled, cut into strips ¾ by 6 inches, and scattered through the package. Approximately 3 pounds of oiled blotter carrying 1.5 pounds of oil were used in each barrel. The material was coarse and only fairly well distributed. The test was made on Grimes Golden, Delicious, Arkansas, and York Imperial apples. The results are given in Table I. Two or more barrels were included in each treatment of each variety.

The apples that were packed with the blotter strips had less than half as much scald as the untreated fruit, but several times more scald than the apples in oiled wrappers. The treatment was not considered a success from the practical standpoint.

TABLE I.—*The effect of oiled barrels, oiled liners, and oiled blotter strips upon the development of scald, 1919 experiments*[a]

Variety, locality, and storage period	Percentage of scald						
		Oiled barrels		Lined with blotters			
	Untreated barrels	Apples next to barrel	Apples in center of barrel	Apples next to blotters	Apples in center of barrel	Blotter strips	Oiled wrappers
Grimes Golden, Rockville, Md., Sept. 4, 1919, to Dec. 31, 1919	80	35	67	25	73	25	0
Delicious, Winchester, Va., Sept. 25, 1919, to Feb. 2, 1920	63					45	18
York Imperial, Leesburg, Va., Nov. 1, 1919, to Jan. 17, 1920	74					12	4
York Imperial, Rockville, Md., Sept. 26, 1919, to Jan. 15, 1920	70			21	48	11	0
Arkansas, Winchester, Va., Oct. 7, 1919, to Jan. 10, 1920	55			8	20	32	1

[a] The records were taken three days after the apples were removed from storage. During the after-storage period the fruit was held at a temperature of approximately 70° F. The percentages show the general severity of the disease, allowance being made for the surface area scalded, and the intensity of the scalds as well as the number of apples affected.

TABLE II.—*The effect of oiled straw, oiled paper, and oiled wrappers upon the development of apple scald, 1923 experiments*[a]

Variety, locality, storage period, and the nature of the oil treatment	Percentage of apples showing—			Degree of scald
	Bad scald	Slight scald	No scald	
Grimes Golden, Rockville, Md., Sept. 13, 1923, to Jan. 15, 1924:				*Per cent*
Untreated	73	25	2	87
Chopped oiled paper, 1 pound per barrel	4	20	76	8
Oiled wrappers	0	23	77	5
York Imperial, Vienna, Va., Oct. 11, 1923, to April 3, 1924:				
Untreated	70	21	9	71
Layers of oiled paper (wrappers)	6	7	87	4
Chopped oiled paper, 1½ pounds per barrel	2	17	81	5
Ribboned oiled paper, 1½ pounds per barrel	11	18	71	9
Chopped straw, unoiled, 4½ pounds per barrel	31	15	54	33
Chopped straw carrying ½ pound of oil; 5¾ pounds of oiled straw per barrel	0	20	80	4
Chopped straw carrying 1 pound of oil; 6 pounds of oiled straw per barrel	1	9	90	2
Oiled wrappers	5	25	70	6
York Imperial, Rockville, Md., Oct. 18, 1923, to Feb. 29, 1924:				
Untreated	94	6	0	76
Layers of oiled paper (wrappers)	7	27	66	8
Chopped oiled paper, 1½ pounds per barrel	2	31	67	7
Chopped oiled paper, 2¼ pounds per barrel	0	22	78	1
Ribboned oiled paper, 1 pound per barrel	0	18	82	1
Ribboned oiled paper, 1½ pounds per barrel	1	26	73	3
Ribboned oiled paper, 2¼ pounds per barrel	0	4	96	0.2
Oiled wrappers	4	19	77	5
Arkansas (Mammoth Black Twig), Inwood, W. Va., Oct. 29, 1923, to March 17, 1924:				
Untreated	79	21	0	89
Ribboned oiled paper, 1 pound per barrel	32	39	29	23
Ribboned oiled paper, 1½ pounds per barrel	0	29	71	6
Ribboned oiled paper, 2¼ pounds per barrel	8	12	80	9
Oiled wrappers	29	30	41	19
Ben Davis, Inwood, W. Va., Oct. 29, 1923, to May 20, 1924:				
Untreated	45	37	18	35
Ribboned oiled paper, 1½ pounds per barrel	0	0	100	0
Oiled wrappers	0	0	100	0

[a] An apple was counted as having slight scald when it had but a slight touch of brown that probably would have little if any effect upon its market value. When worse than this it was counted as having bad scald. The percentages in the last column give the general severity of the disease in one set of figures allowance being made for the surface area scalded and the intensity of the scald, as well as the number of apples affected.

OILED STRAW

In 1923, experiments were conducted with oiled wheat straw. The straw was cut into lengths of 1 or 2 inches, sprayed with oil and allowed to stand a week or more before using. It seemed quite oily immediately after the spraying but in a few days the oil was so completely absorbed by the straw that it was scarcely noticeable, especially in the cases of the lighter applications. One-half pound to one pound of oil was used with the straw in each barrel of apples. The test was carried out on two separate lots of York Imperial and the results are reported in Table II.

The straw punctured some of the apples and caused a slight increase in the number of rots. The dust from the straw was inclined to stick to the apples after removal from storage and detracted from their appearance. The straw itself, without the oil, seemed to have some value in scald control, reducing the disease to about half the amount found on the untreated barrels. The oiled straw gave practically complete scald control, making even a better showing than the oiled wrappers. It should be noted, however, that a larger quantity of oiled material was used in the case of the straw than with the wrappers.

SHREDDED OILED PAPER

In 1923 several of the companies that were manufacturing oiled wrappers also prepared some form of shredded oiled paper. Two different brands of this paper were tested in the experiments reported in Table II. The chopped paper had been cut into pieces about 1 inch wide and 1 to 2 inches long. It was well oiled and tightly pressed together, making it difficult to get the mass of paper in a finely divided condition suitable for thorough distribution in the package. The ribboned paper consisted of strips about one-fourth inch wide and 10 to 12 inches long. It was well oiled but loose and springy and seemed to enmesh the apples more thoroughly than the chopped paper. It also gave a nice appearance to the package. Both brands of paper were thoroughly and evenly distributed through the barrel. The experiment was conducted on Grimes Golden, Arkansas, Ben Davis, Yellow Newtown, and on two separate lots of York Imperial apples. Two or more barrels were included in each treatment of each variety. The results are reported in Table II.

The weight of oiled wrappers that would be required for wrapping a barrel of apples would vary with the size of the apples and the size and quality of the wrappers but would probably average about 1½ pounds. Where 1½ pounds of shredded oiled paper were evenly distributed through the barrel the average scald control was almost identical with that secured with the oiled wrappers and with the Arkansas variety it was distinctly better than with the wrappers. With 1 pound of shredded oiled paper to the barrel the results on Grimes Golden and Arkansas were poorer than those with the oiled wrappers, but the 1-pound treatment gave very satisfactory results on York Imperial. With 2¼ pounds of shredded paper to the barrel the results on the Arkansas were no better than with 1½ pounds, but with the York Imperial the 2¼ pounds gave better scald control than any other treatment. In general, the results indicate that shredded oiled paper, well distributed in the barrel, will give practically as good scald control as an equal weight of oiled paper used as wrappers.

DISCUSSION

The foregoing experiments give some additional information in regard to the nature of apple scald and furnish practical suggestions for the control of the disease in the barrel package.

The oiled barrels and the oiled liners were a failure although 1 pound of oil was used to the barrel. Three pounds of oiled blotter strips carrying 1.5 pounds of oil to the barrel gave very poor scald control. Five to six pounds of oiled straw carrying one-half to 1 pound of oil gave good scald control. Shredded oil paper and layers of oiled wrappers, used at the rate of 1.5 pounds to the barrel and carrying about 5 ounces of oil to the barrel in each case, gave practically the same scald control as was obtained by wrapping each apple in an oiled wrapper. The quantity of paper and oil per barrel was approximately the same with the layers and the shredded paper as where each apple was wrapped separately. The results indicate that it is not essential to scald control, at least in the barrel package, to have the apples actually inclosed in wrappers or to have the oiled material in contact with the apples at every point. On the other hand, the failure of the oiled barrels, the oiled liners, and the oiled blotter strips with their heavy applications of oil, indicates that the oiled material must be in close proximity to

the apples and that the distribution and the surface exposure of the material are even more important than the amount of oil carried.

Of all the treatments tested, the shredded oiled paper offers the greatest practical possibilities for the barrel package. The layers of oiled wrappers gave almost as good scald control, but the treatment as carried out in the experiments would not be adapted to practical operations. The apples were packed in definite layers, thus giving a more uniform contact between the wrappers and fruit than would be likely to be obtained under the customary methods of packing. The careful placing of the apples and the wrappers as packed in the experiment took almost as much time and labor as would have been required to actually wrap the fruit. The use of a larger and thicker sheet instead of the individual oiled wrappers would mean a saving in labor, but there would be less surface exposure and the additional strength and stiffness in the paper would result in less contact between the paper and the apples and would also probably mean a more open pack that might later become slack in storage. The method could hardly be used with satisfactory results without considerable care to place the apples in layers.

The experimental results indicate that under average conditions 1½ pounds of chopped or ribboned oiled paper to the barrel will give fairly satisfactory scald control provided it is well distributed in the package. Various methods have been suggested for securing this distribution under commercial packing-house conditions. One of the great obstacles in securing satisfactory results is the prevailing custom of running in too large quantities of apples at one time. If the apples were added a peck at a time and each addition followed by a sprinkling of oiled paper it should be readily possible to secure a good distribution of the material. This method would necessarily make some delay in packing, but if the apples were added in smaller quantity and the barrel shaken after each addition the final result should be a tighter pack with less necessity for crushing the apples at the tail of the barrel and probably a saving of the cost of plugging the packages later in the season. The most practical method of applying the oiled paper will of course vary with orchard and packing-house conditions.

SUMMARY

Various oiled materials have been tested for the control of scald in the barrel package.

Oiled barrels and oiled liners have reduced scald on the outside apples but have had little effect upon the package as a whole.

Oiled straw, shredded oiled paper, and layers of oiled wrappers have given practically as good scald control as wrapping the apples in oiled paper.

The success of these various treatments has apparently depended greatly upon the thoroughness with which the oiled material has been distributed in the package.

The shredded oiled paper furnishes the most promising method of scald control for the barrel package.

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THE GREENHOUSE LEAF-TYER, PHLYCTAENIA RUBIGALIS (GUENÉE)[1]

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INTRODUCTION

The larvae of a small moth known as the greenhouse leaf-tyer,[2] *Phlyctaenia rubigalis* (Guenée),[3] may be classed among the more important and destructive enemies of chrysanthemum, cineraria, snapdragon, and a long list of other ornamental and greenhouse plants. According to recent authoritative reports received by the Bureau of Entomology, this pest has, in several instances, occasioned complete destruction of the plants attacked. The need for more complete information regarding its life history and control under greenhouse conditions, together with the frequent complaints and repeated requests for more effective means of control, prompted the authors to make the present study of this insect as a greenhouse pest.

NATURE OF INJURY

The injury results almost exclusively from the feeding done by the larvae. Since the length of the larval period is slightly more than the combined egg and pupal stages, ample time is provided for them to become exceedingly troublesome and cause considerable damage. Feeding is normally restricted to the lower surface of the leaves, although on some host plants, as cineraria and chrysanthemum, the larvae have been observed to attack the upper surface and the bloom as well. At first the larvae skeletonize the foliage by eating small holes in the underside of the leaves so that only the upper epidermis remains intact. The injured areas which become pitted later coalesce and present a silvery appearance. As they grow older the larvae may devour the entire leaf tissue. As their common name implies, they spin a slight silken web, or tie two contiguous leaves together to form a shelter within which they remain while feeding. They develop voracious appetites, and when present in considerable numbers cause severe injury to the plants attacked, not only disfiguring them, but actually destroying the leaf surface to such an extent that the plants die (Pl. 1, A, B). When the food supply becomes exhausted they crawl away to other plants, and since they are able to feed on so many different varieties the infestation is spread very rapidly throughout the houses.

ECONOMIC IMPORTANCE

Although an apparently well-established pest in this country, the leaf-tyer intermittently causes such severe injury on certain greenhouse crops, especially chrysanthemums and cinerarias, that it demands prompt attention when a house has become infested. Considered primarily as a greenhouse pest, the citations below give some idea of the seriousness and the extent of damage which it may inflict. These include only a few of the more recent complaints and appeals for assistance which have been received by the Bureau of Entomology, although numerous early records are on file which might be mentioned further to emphasize the potentialities of this insect.

In 1909 it was reported from Portland, Oreg., as causing serious injury to violets in greenhouses, and in the same year a correspondent from Adrian, Mich., reported the larvae as being "present by millions on chrysanthemums, and devouring the plants so that it was impossible to secure cuttings." In 1912 a report from Huntsville, Ala., indicated that "two houses of chrysanthemums were stripped of their leaves, which only two weeks before had shown promise of a fair crop." In 1919 the senior author visited a florist in Vincennes, Ind., and

[1] Received for publication April 22, 1924—issued January, 1925.

[2] Sometimes referred to as "the parsnip webworm," "the chrysanthemum leaf-skeletonizer," and "the celery borer."

[3] Order Lepidoptera, family Pyralidae, subfamily Pyraustinae.

saw the destruction which this pest is capable of causing. In this instance the entire crop of chrysanthemums in two houses was a complete loss. During 1921 the leaf-tyers were reported as common in greenhouses throughout the Middle West and at Flint, Mich., where they caused severe injury to cinerarias.

FOOD PLANTS

Among the preferred hosts the following flowering and ornamental plants most susceptible to their attacks may be listed: Common chrysanthemum (*Chrysanthemum hortorum*), cineraria (*Senecio cruentus*), violet (*Viola tricolor*), rose (*Rosa* spp.), carnation (*Dianthus caryophyllus*), calendula (pot-marigold) (*Calendula officinalis*), sweet pea (*Lathyrus odoratus*), marguerite (*Chrysanthemum frutescens*), geranium (*Pelargonium hortorum*), snapdragon (*Antirrhinum* spp.).

In addition, they are more or less injurious to primrose (*Primula* spp.), ageratum (*Ageratum houstonianum*), marigold (*Tagetes* spp.), heliotrope (*Heliotropium peruvianum*), common petunia (*Petunia hybrida*), begonia (*Begonia* spp.), canna (*Canna indica*), dahlia (*Dahlia rosea*), wallflower (*Cheiranthus* sp.), nasturtium (*Tropaeolum* spp.), abutilon (*Abutilon* spp.), cyclamen (*Cyclamen persicum*), anemone (*Anemone japonica*), sage (*Salvia officinalis*), moonflower (*Calonyction aculeatum*), azalea (*Azalea* spp.), sultan snapweed (*Impatiens sultana*), spiderwort (*Tradescantia fluminensis*), blessed thistle (*Cnicus benedictus*), kenilworth-ivy (*Linaria cymbalaria*), ivy groundsel (*Senecio mikanioides*), ground-ivy (*Nepeta hederacea*), passion flower (*Passiflora caerulea*), feverfew camomile (*Matricaria parthenoides*), plumbago (*Plumbago capensis*), redspray ruellia (*Ruellia amoena*), (*Tydaea*) *Isoloma ocellatum*, lobelia (*Lobelia erinus*), speedwell (*Veronica* spp.), common lantana (*Lantana camara*), slender deutzia (*Deutzia gracilis*), goatsrue senna-pea (*Swainsona galegifolia*), China aster (*Callistephus chinensis*), coleus (*Coleus blumei*), fuchsia (*Fuchsia speciosa* [*hybrida*]), *Justicia furcata*, canary broom (*Cytisus canariensis*).

DISTRIBUTION

The greenhouse leaf-tyer is widely distributed throughout the United States, Canada, Central America, and South America, and is definitely reported as occurring in the District of Columbia and in the following States: Alabama, California, Colorado, Connecticut, Florida, Illinois, Indiana, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Mississippi, Missouri, Nebraska, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, Texas, Vermont, Virginia, West Virginia, and Wisconsin.

SYNONYMY

Since 1854, when this American species was originally described by Guenée (*8, p. 398*)[4] as *Scopula rubigalis*, it has frequently been confused with the closely related European species known as *Phlyctaenia ferrugalis* Hübner-*Botys oblunalis*, described by Lederer (*10, p. 469*), and *Botis harveyana*, described by Grote (*7, p. 104–105*) in 1877, were regarded by Hampson as synonymous with the American species. In 1899 Hampson (*9, p. 242, 243*) catalogued *Pionea rubigalis* and *Pionea ferrugalis* as distinct species. Two years later both Slingerland (*13, p. 159*) and Chittenden (*3, p. 7*) used the name *Phlyctaenia rubigalis* in describing the greenhouse species. In 1902, however, Fernald (*in* Dyar, *5, p. 387*) reduced all these species to synonymy with Hübner's *ferrugalis*, a classification which has since been followed in economic literature down to the present time. Barnes and McDunnough in 1917 (*1, p. 133*) also regarded the two species as identical. The specimens used in these experiments have been identified by Messrs. Busck and Heinrich as *Phlyctaenia rubigalis* Guenée.

The following are the more important references to *Phlyctaenia rubigalis*, and its synonyms:

Scopula rubigalis Guenée, 1854, Spec. Gen. 8: 398.

Botys oblunalis Lederer, 1863, Wien. Ent. Monatschr., 7: 372, 469.

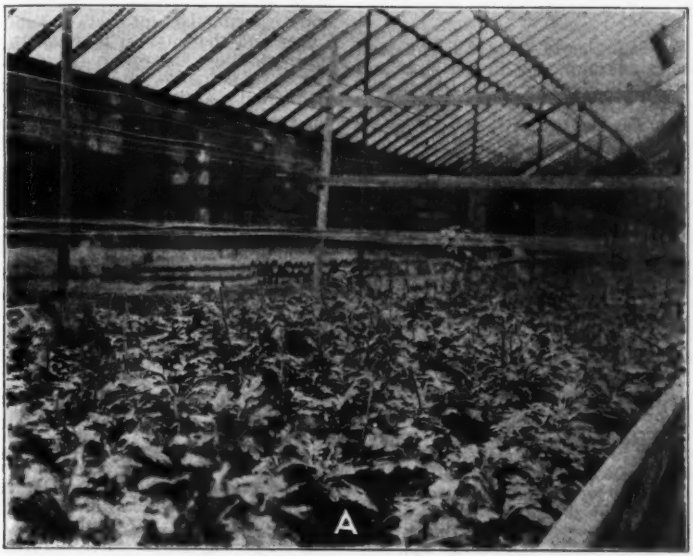
Botis harveyana Grote, 1877, Canad. Ent., 9: 104–105

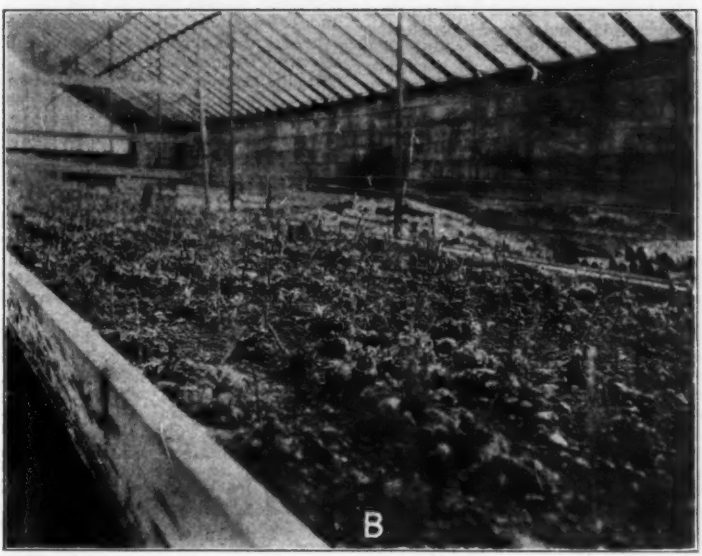
Pionea rubigalis Hampson, 1899, Proc. Zool. Soc. London f. 1899, p. 242.

Phlyctaenia rubigalis Chittenden, 1901, U. S. Dept. Agr., Div. Ent. Bul. 27, p. 7; Slingerland, 1901, N. Y. Cornell Agr. Exp. Sta. Bul. 190, p. 159.

Phlyctaenia ferrugalis Fernald, 1902, not Hübner, *in* Dyar's List N. Amer. Lep., p. 387; Barnes and McDunnough, 1917, not Hübner, Check List Lep. Bor. Amer., p. 133.

[4] Reference is made by number (italic) to "Literature cited" p. 158.





The Greenhouse Leaf-Tyer Plate 1

A.—House of chrysanthemums showing plants uninjured and in normal condition

B.—House of chrysanthemums showing plants severely injured by the greenhouse leaf-tyer

SYSTEMATIC DESCRIPTION OF PHLYCTAENIA RUBIGALIS GUENEE

For a number of years this American species has appeared in our lists and literature under the name *Phlyctaenia ferrugalis* Hübner, on the supposition that it was identical with the European species of that name.

On this supposition Fernald (*in* Dyar, *5, p. 387*) wrongly listed *ferrugalis* as an American species and placed *rubigalis* as one of its synonyms, although Chittenden (*3, p. 7–26*), previously had pointed out certain differences in the two species. He, as well as Slingerland (*13, p. 159–164*), correctly referred to the American species as *rubigalis* Guenée, following Hampson's (*9, p. 242*) determination.

A comparison of the genitalia of American and European specimens at once proved them two different species. *Phlyctaenia rubigalis* occurs throughout the United States, Central America, and South America. As far as we know *P. ferrugalis* does not occur anywhere on this hemisphere. All specimens which we have seen under this name from North and South America are true *rubigalis*.

The two species can be distinguished on several characters. Although the moths are very similar in size and color and difficult to separate with certainty without examining the genitalia, the outer transverse line on the forewing has a slightly different course, being more angulate on the costal edge than in *ferrugalis* and more outwardly curved on its dorsal half. The faint, oblique, dusky shade on the outer fourth of the forewing in *ferrugalis* is hardly present, or at least very faint, in *rubigalis*, and the marginal black dots are more distinct in *rubigalis* than in the European species.

An examination of either the male or female genitalia at once proves the distinctiveness of the two species. In *rubigalis* the tegumen of the male genitalia is narrower and more elongated than that of *ferrugalis* which is more abruptly shouldered. The differences in the anellus are very striking. In *ferrugalis* it is a simple, nearly rectangular plate, with two upper corners triangularly produced and with the incision between these broad and shallow; while in *rubigalis* it is a much more ornate structure, with the two upper triangular projections much longer and the interval between them correspondingly narrower and deeper, and with two branched and strongly scobinated lateral arms. (Compare fig. 1, A and B.)

The harps of *ferrugalis* are somewhat narrower than those of *rubigalis* and contain a cluster of very short, stout spines on the sacculus, represented in *rubigalis* by an ill-defined and more diffused patch of fine hairs; the clasper is stouter in *ferrugalis* than in *rubigalis* and penis contains only one strong, straight cornutal spine, while in *rubigalis* there are two, one of which is curved. Other minor differences on the male genitalia are shown in Figure 1, A and B.

In the female of *ferrugalis* the signum of the bursa copulatrix is considerably broader in proportion to its length than that of *rubigalis* and the chitinization around the ductus bursae and the genital opening is broader and more extended. (For differences in detail compare fig. 2, C and D.)

A single superficial color difference at once separates the larvae; in the European species there are two distinct and conspicuous black spots on each side of the thoracic shield, shaped like a crude exclamation point, while in *rubigalis* there is only a single elongate spot. In occasional specimens this may be partly broken up into two, but on the whole the character holds.

A detailed description of the various stages of *Phlyctaenia rubigalis* follows.

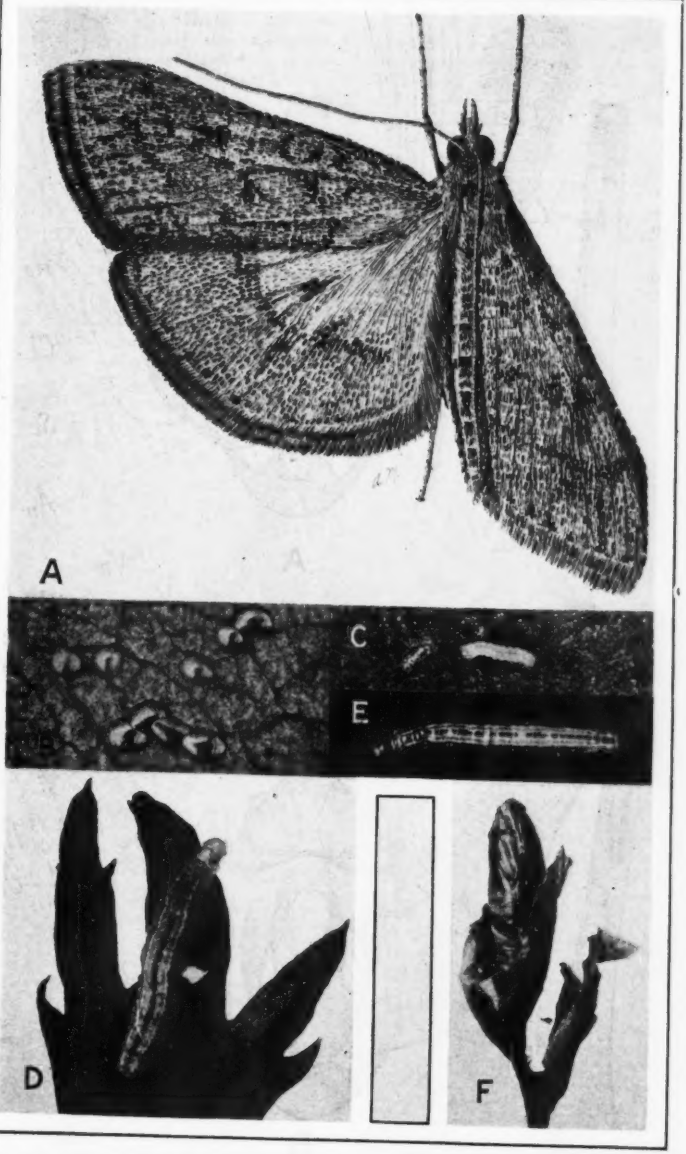
EGG

Egg 0.8 mm. long by 0.6 mm. broad, ovate, flattened, shiny and iridescent, whitish when newly laid, translucent, surface finely and irregularly reticulated.

The eggs are generally laid on the underside of a leaf, singly or in groups of from 2 to 12 or more, overlapping one another (Pl. 2, B).

LARVA

The larva (Pl. 2, C, D, E) is slender, cylindrical, tapering toward both extremities; without secondary hair; body pale green with a narrow, darker



The Greenhouse Leaf-Tyer

Plate 2

Phlyctaenia rubigalis: A.—Moth. B.—Egg clusters on portion of rose leaf. C.—Newly hatched larva. D.—Full-grown larva on marguerite leaf. E.—Full-grown larva. F.—Rolled marguerite leaf torn to expose pupa within. (All greatly enlarged)

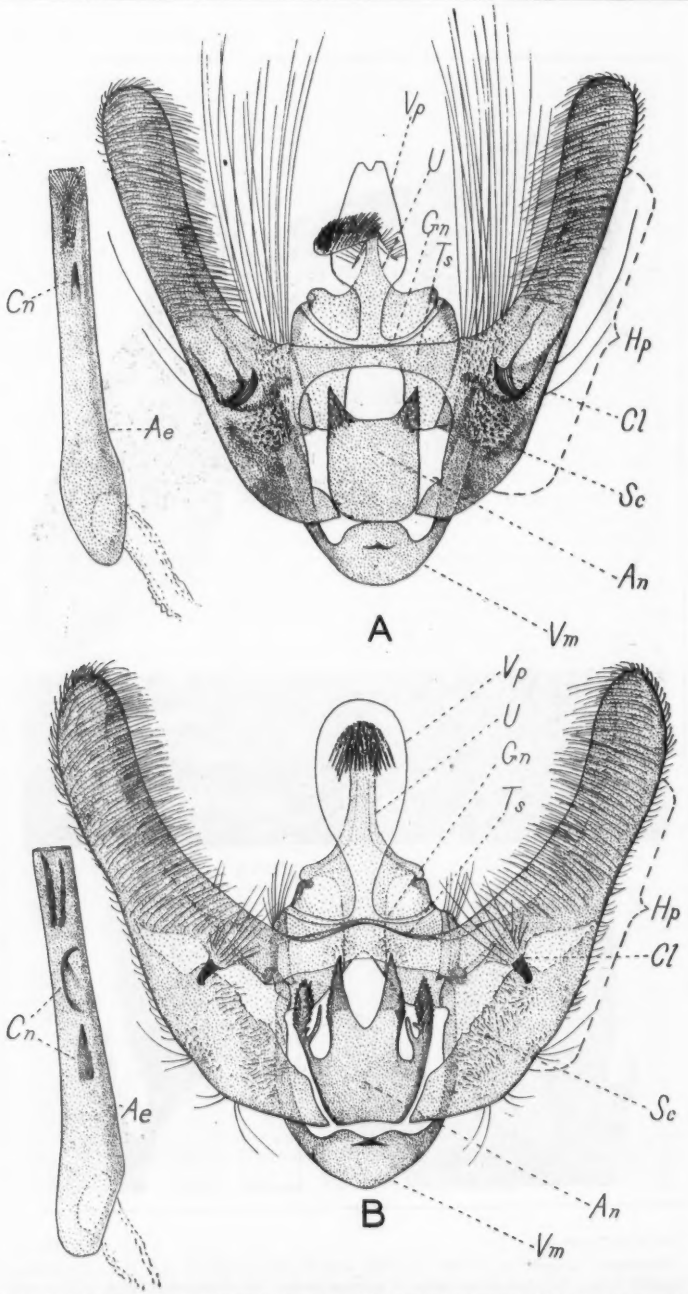


FIG. 1.—A, Male genitalia of *Phlyctaenia ferrugalis*, with detached aedoeagus at left; B, the same o *P. rubigalis*. *Ae*, Aedoeagus; *An*, anellus; *Cl*, clasper; *Cn*, cornuti; *Gn*, gnathos; *Hp*, harp; *Sc*, sacculus; *Ts*, transtilla; *U*, uncus; *Vm*, vinculum; *Vp*, ventral plate

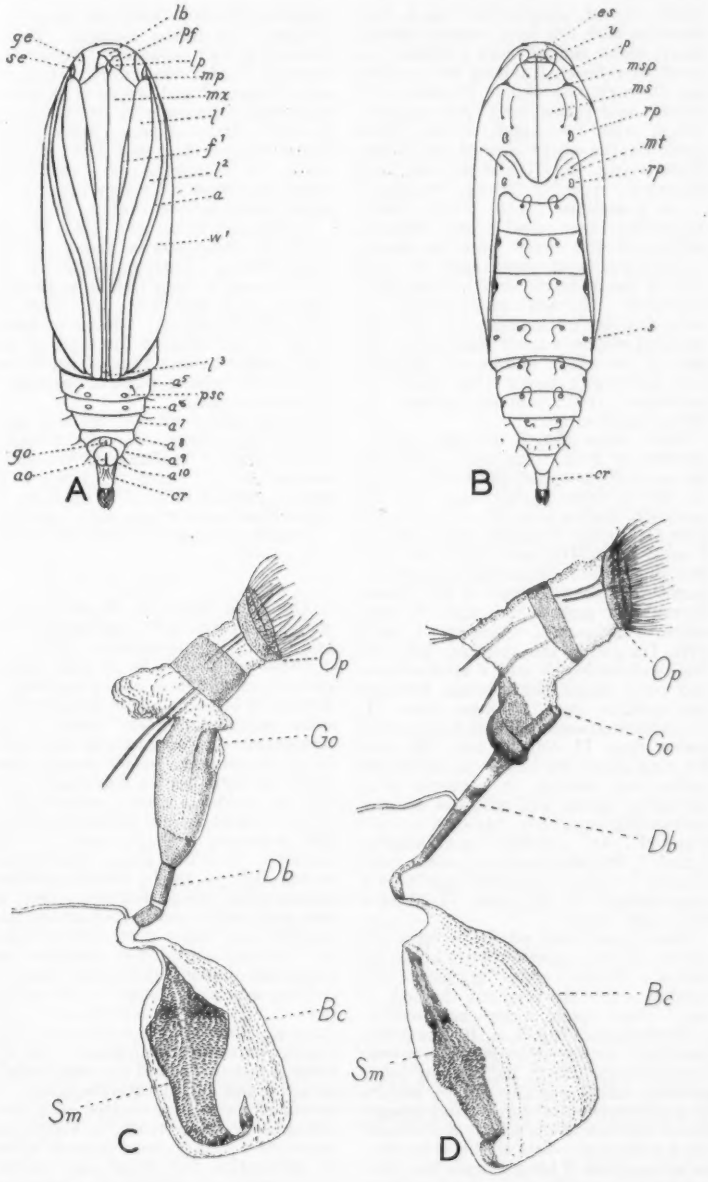


FIG. 2.—A, Pupa of *Phlyctaenia rubigalis*, ventral view; B, pupa of *P. rubigalis*, dorsal view; C, female genitalia of *P. ferrugalis*; D, female genitalia of *P. rubigalis*. Explanation of symbols applied to genitalia: *Bc*, Bursa copulatrix; *Db*, ductus bursae; *Go*, genital opening; *Op*, ovipositor; *Sm*, signum. Explanation of symbols applied to pupa: *a*, Antenna; *ao*, anal opening; *cr*, cremaster; *es*, epicranial suture; *f*, femur of prothoracic leg, *ge*, glazed eyepiece; *go*, genital opening; *lb*, labrum; l^1, prothoracic leg; l^2, mesothoracic leg; l^3, metathoracic leg; *lp*, labial palpi; *mp*, maxillary palpus; *ms*, mesothorax; *msp*, mesothoracic spiracle; *mt*, metathorax; *mx*, maxilla; *p*, prothorax; *pf*, pilifer; *psc*, proleg scar; *rp*, reniform pit; *S*, spiracle; *se*, sculptured eyepiece; *v*, vertex, w^1, forewing; a^5–a^{10}, abdominal segments 5 to 10.

green, dorsal longitudinal band, bordered on each side by a broader whitish band; under side of body yellowish (or greenish yellow), tracheae white showing through the skin. Thoracic legs slender and rather long; pale greenish yellow with two small, round, black spots on the outer side of the tibiae. Prolegs (fig. 3, D) slender and long stemmed; crochets (36–42) triordinal, in a penellipse. Anal fork absent. Tubercles and anal and thoracic shields of the body color; a single, conspicuous oval black spot on each side of the thoracic shield, lying back of seta 1b. Spiracles small, round, but very faintly pigmented; on 8th abdominal segment more than twice the size of the other abdominal spiracles and noticeably larger than those on prothorax. Skin smooth, except for the primary setae.

Body setae (fig. 3, E) pale yellow, moderately long. Prothorax *with only two setae on prespiracular shield* (4 and 5); II^a a trifle higher than I^a; II^b markedly higher than I^b, nearer to II^a than II^a is to I^a; I^b as near (or nearer to) I^c as I^c is to II^c, remote from I^a; only two punctures distinguishable (y and z), puncture y dorsocaudad of I^a. Mesothorax and metathorax with VI unisetose. Abdominal segments 1 to 8 with III above the spiracle; III^a not distinguishable; IV and V approximate and on a single chitinization beneath the spiracle; seta I longer than II, on abdominal segments 1 to 5 somewhat higher than II, but on 6th, 7th, and 8th abdominal segments on about the same level, absent on segment 9 of abdomen; group VII trisetose on proleg-bearing segments, bisetose on abdominal 7, and unisetose on abdominal 8 and 9; 9th abdominal segment with IV and V united in a single hair closely approximate to III; seta VI present and very long.

Head small; pale whitish or greenish yellow, faintly mottled with brownish yellow. Trophi very slightly pigmented. Ocellar pigment defined as small black spots under each ocellus.

Head capsule (fig. 3, A, B) somewhat flattened; ovate-orbicular in outline viewed from above; as wide as long; greatest width slightly before middle of head; incision of dorsal hind margin about one-fourth the width of the head (or a trifle less); distance between dorsal extremities of hind margin less than one-half the width of the head. Frons broad; longer than broad; reaching beyond middle of head. Adfrontal sutures extending to incision of dorsal hind margin. Longitudinal ridge short; considerably less than one-third the length of frons. Ocelli six; lenses well defined. Epistoma normal. Frontal punctures well separated; slightly forward of frontal setae; only distinguishable in cleared and prepared mounts of the head; distance from frontal seta F^1 to first adfrontal seta (Adf^1) greater than between Adf^1 and Adf^2; approximate to beginning of longitudinal ridge; puncture Adf^a very faint, somewhat nearer to Adf^2 than to Adf^1.

Epicranial punctures, seta G^1, and setae of ultraposterior group not distinguishable. Anterior setae (A^1, A^2, A^3) forming a very obtuse angle lying almost in a line with L^1. Posterior setae (P^1, P^2) slightly behind middle of head; P^1 well behind the level of Adf^1 and a trifle behind that of L^1; P^2 well behind the level of place of juncture of adfrontal ridges.

Ocellar setae (O^1, O^2, O^3) well separated; O^1 ventrad of ocelli 2 and 3, approximate to ocellus 3; O^2 ventrad of ocellus 1; O^3 anteroventrad of O^2, remote, farther from O^2 than from O^1. Subocellar setae triangularly grouped.

Length of full-grown larva 17–19 mm.

PUPA

The pupa (fig. 2, A, B; Pl. 2, F) is smoky brown with intersegmented areas of abdomen (especially from abdominal segments 5 to 7) pale yellow; smooth, except for a slight rugosity on dorsum of 7th segment of abdomen and some rather prominent dorsal setae; mesothorax and metathorax with a distinct, prominent, rather large, chitinized reniform pit on dorsum on each side of middle; wings extending to ventro-caudal margin of fourth abdominal segment; cephalic end bluntly rounded, tapering from mesothorax, vertex distinct, small; labrum, pilifers, and maxillary palpi well developed; labial palpi very small; prothoracic and mesothoracic legs not extending cephalad between sculptured eyepiece and antennae; maxillae broad and long, extending nearly the length of the wings, having only tips of metathoracic legs exposed; femora of prothoracic legs clearly exposed; prothoracic legs extending more than half the wing length; mesothoracic and metathoracic legs and antennae extending to tips of wings; proleg scars clearly visible on abdominal segments 5 and 6; mesothoracic spiracle discernible, but small and narrow, not prominently chitinized; abdominal spiracle distinct, not appreciably produced, small and round; anal and genital openings slitlike in both sexes; anal rise very slight, unarmed; cremaster present, prominent, moderately long,

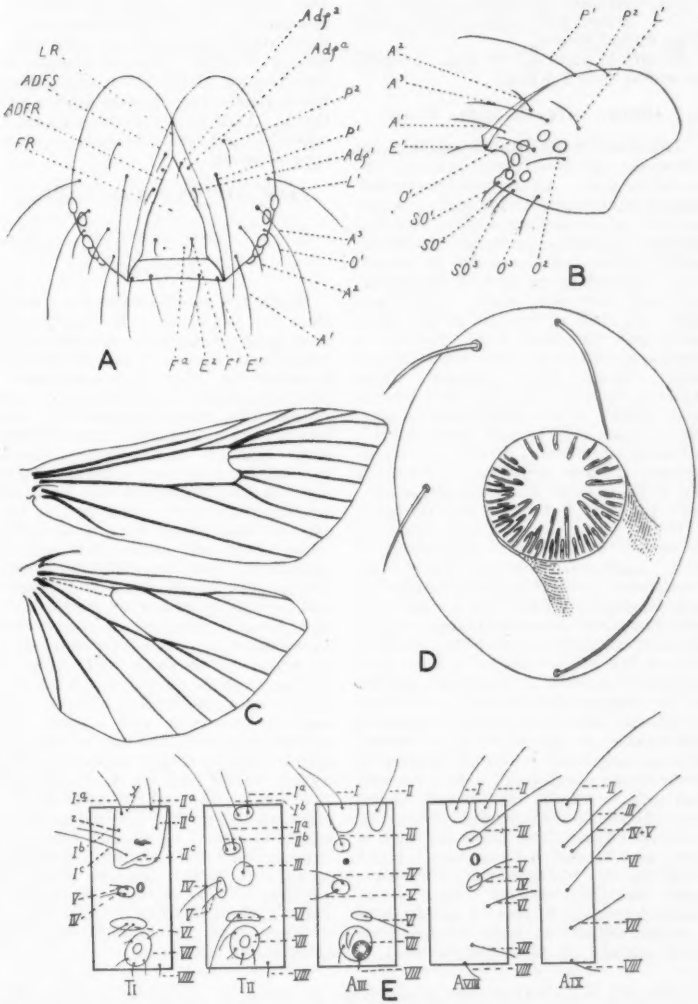


FIG. 3.—A, Head capsule of larva of *Phlyctaenia rubigalis*, front view; B, same, side view; C, Wing venation of same; D, Abdominal proleg of larva; E, Map of body setae of larva. Explanation of symbols: A^1, A^2, A^3, setae of anterior group of epicranium; Adf^1, Adf^2, Adf^a, adfrontal setae and puncture of epicranium; *ADFR*, adfrontal ridge of larval head; *ADFS*, adfrontal suture of larval head; E^1, E^2, epistomal setae; F^1, F^a, adfrontal setae and puncture of epicranium; *FR*, frons of epicranium; *L*, lateral seta group of epicranium; *LR*, longitudinal ridge of epicranium; O^1, O^2, O^3, setae of ocellar group of epicranium; P^1, P^2, setae of posterior group of epicranium; SO^1, SO^2, SO^3, setae of subocellar group of epicranium

blunt, spatulate, extremity squarely cut armed with eight stout, rather long, curled spines.

Length of pupa 8.5–9 mm.; breadth at widest part 2.5 mm.

ADULT. (FIG. 3, C; PL. 2, A)

Antennae two-thirds the length of the forewings, ochreous fuscous, shortly ciliate in the male. Labial palpi porrected; second joint long with elongate triangular tuft of projecting scales; terminal shorter, smooth, porrected, pointed; partly hidden by the scales on second joint; reddish ochreous with the underside and inner side white. Maxillary palpi not half as long as labial palpi, porrected, terminal joint ending in small spreading tuft of reddish ochreous scales, tongue long, spiraled, white scales on base. Eyes large and prominent, black. Ocelli rather conspicuous, set in black. Face and head reddish ochreous edged with whitish ochreous. Thorax reddish ochreous. Forewings (fig. 3, C) smooth, elongate, triangular, apex pointed, termen nearly straight; no fovea; twelve veins, 8 and 9 stalked; 10 closely approximate throughout, 7 closely approximate at base, 4 and 5 approximate, 3 slightly before angle of cell, 1b simple; reddish ochreous with faint blackish fuscous markings; a serrate and angulated, transverse, blackish fuscous line crosses the wing from just beyond the middle of costa and edges of an "8"-shaped blackish spot on the end of the cell; another serrate, transverse line begins at apical third of costa; strongly angulated costal half outwardly curved on dorsal half; a dark fuscous spot on the middle of the cell, and a series of small black marginal dots along terminal edge. Cilia ochreous with a basal and medial fuscous line. Hind wings (fig. 3, C) broader than forewings, costa straight, termen and dorsum evenly rounded; 8 veins; 4 and 5 closely approximate at base, connate or short stalked; 3 approximate to 4, 7 and 8 stalked, 8 anastomozed with 7 beyond the cell, 6 approximate to 7 to their stalk; lower vein of cell without pecten; whitish ochreous, shaded with two fuscous discal spots and an angulated, transverse, fuscous, lineal, apical third. Abdomen whitish ochreous, legs whitish, hind tibiae with outer median spur obsolete.

LIFE HISTORY AND HABITS [5]

ADULT STAGE

Emergence

When the moth is about to emerge from the pupal case the ventral surface splits along the margins of the wing sheaths so as to permit the moth to make its exit. This operation requires approximately 4 to 5 minutes. At first the wings appear very small and distorted, but after some fluttering they become very convex, almost balloonlike in appearance, and gradually become flattened out until they are fully expanded. During this process the moth has been observed to crawl about at times, although normally it remains rather inactive. Finally the wings relax and come to rest perpendicularly over the back, but they are still soft and moist and about 45 minutes elapse before they are fit for flight. The moth (Pl. 2, A) has a wing expanse of three-fourths of an inch, is of a pale brown or rusty color, marked crosswise with darker lines, and when at rest assumes a characteristic triangular shape, measuring three-eighths of an inch at its widest part. The usual time of emergence is at night, since only in a few instances were moths observed to emerge during the daytime, and the maximum emergence appears to occur between dusk and daylight. Observations, as shown in Table I, indicate that it takes from 36 to 55 minutes to complete the whole operation of emergence.

TABLE I.—*Records on time of emergence of adults of Phlyctaenia rubigalis*

Date	Number of specimens	Splitting of pupal case	Free from pupal case	Wings expanded	Ready for flight	Duration
1921						*Minutes*
Jan. 20	1		10.30 a. m.	10.35 a. m.	11.20 a. m.	
Apr. 21	1	8.55 a. m.	9.00 a. m.	9.12 a. m.	9.40 a. m.	45
Apr. 27	1	8.36 p. m.	8.40 p. m.	8.47 p. m.	9.12 p. m.	36
Apr. 28	1	7.05 p. m.	7.11 p. m.	7.25 p. m.	8.00 p. m.	55

[5] Most of the observations of the life-history studies were made from the specimens under confinement and these results were eventually compared with observations taken from general infestations.

Longevity

The adults are relatively long lived, their longevity ranging up to a maximum of 23 days. Out of a total of 205 moths confined with plants in insect-rearing cages 124 died within 10 days, 80 lived from 11 to 18 days, and 1 died on the 23d day. It was found that the average life of a female was from 9 to 10 days, while that of a male was only 4 to 5 days. Thirteen moths kept in confinement without a plant lived from 3 to 9 days, with an average life of about 6 days.

Activity

The adults are nocturnal in habit, being more active at night, especially at dusk, when they may be observed flying in a zigzag fashion from plant to plant or swarming near the glass under the eaves. During the daytime they show much less activity and remain concealed, resting inconspicuously on the under side of the foliage or under the benches, or in other places where they are least likely to be disturbed; when alighting on a plant they immediately crawl to the under side of the leaves. Observations on the proportion of sexes in the third generation showed that there were about two females to every male, but in several later generations more males emerged.

Egg Deposition

Soon after mating egg deposition commences and may continue for about two weeks, the maximum number being laid during the first few days and the number decreasing rapidly during the following week. In the case of a few individuals which lived three weeks or more, practically no eggs were laid during the last week. The female moth deposits her eggs singly or in clusters (Pl. 2, B) on the under side of leaves during the night, egg laying rarely commencing until 24 hours after emergence.

The maximum number of eggs laid per individual was not definitely determined because the adults would usually die within two days whenever they were confined singly. In two instances only 42 and 80 eggs, respectively, were deposited within five days after emergence and the moths died three days later. It was necessary, therefore, to confine a number of individuals in a cage at one time. Under these conditions similar difficulty was experienced in securing satisfactory averages, as some of the moths would die after being in confinement for several days. The most reliable records were taken from the adults of the third generation and are given in Table II.

TABLE II.—*Egg-laying records for adults of the third generation of Phlyctaenia rubigalis*

Date of emergence	Number of moths emerged	Date of oviposition	Moths alive	Number of eggs deposited
Apr. 25	37	Apr. 26	37	60
26	*29	27	66	307
		28	48	42
		29	43	250
		30	42	174
		May 1–2	41	133
		3	40	344
		4	40	60
		6	27	0
		7	20	0
		9	1	0
		15	0	0
Total				1,370

* Sixteen moths removed for experimental use.

In only one case was deposition observed during the day. Fresh plants placed in cages at 9 a. m. and examined in the evening were normally devoid of eggs, but if plants were left in all night many eggs were usually deposited on them. These records were corroborated by actual observations of 20 moths confined with a calendula plant inside a lantern globe during the night of April 27, 1921. Eggs were deposited on both surfaces of the leaf and on the lantern globe at the following hours: 9.30, 9.50, 10.15, 10.30 p. m., and 12.15 and 1.25 a. m. By 4.25 a. m. the moths had become inactive and no more eggs were deposited that day. When ready to lay eggs the female bends the tip of her abdomen toward the leaf surface, after which the tube of the ovipositor is extended. The eggs are then forced out as small translucent droplets which the moth, with the aid of the third pair of legs, flattens out by pressing them so that they assume a scale-like appearance. During this operation the ovipositor is moved with a quick, nervous action from left to right, whereby the eggs are placed in successive rows forming regular clusters or patches (Pl. 2, B) which may contain as many as 19, arranged in double or triple rows. Observations based on a total of 1,933 eggs from 4 successive generations indicate that the number per cluster is normally less than 10.

TABLE III.—*Range of incubation period of eggs of Phlyctaenia rubigalis during six generations*

Generation	Total number of eggs deposited	Incubation period		
		Minimum	Maximum	Average
		Days	*Days*	*Days*
Second	142	5	9	7.0
Third	313	8	10	9.0
Fourth	3,400	5	10	7.5
Fifth	(a)	5	6	5.5
Eighth	570	4	7	5.5
Ninth	142	4	6	5.0
Average				6.58

a Few.

EGG STAGE

Incubation

Consulting Table III, it will be seen that the incubation period varies, being from 4 to 10 days in length and averaging 6.5 days. It was also found that all the eggs do not necessarily hatch at the same time. From a total of 50 eggs deposited on a marguerite plant March 10, 17 hatched on March 19, or 9 days later, while the remaining 33 did not hatch until the following day. Another lot of eggs deposited on the same date on other plants began hatching on March 18, or 8 days after deposition.

Development

The time required for the embryonic development of the young larvae was observed to vary from 4 to 10 days, depending, no doubt, on the temperature and other factors. It was difficult to observe the earlier changes without the aid of a microscope, because of the reticulated structure of the shell, which is iridescent. However, several days after deposition the shell becomes more transparent, and the outer margin more distinct. Shortly before hatching the eggs appear more plump, and segmentation can be recognized.

Newly deposited eggs appear to have a vague granular, cellular structure. The outline of the cells soon becomes more distinct, and definite layers of them are grouped in the periphery of the egg. Invagination takes place at one side, and these cells appear to lose their identity and break down, evidently for the purpose of forming the various organs and internal structures of the body. The first conspicuous change observed was the presence of orange colored spots at one end of the egg, which soon developed into reddish-brown mouth parts. Even before the outlines of the head were apparent, the mandibles could be seen, opening and closing. The eye spots can be seen gradually growing darker, and the legs, prolegs, bristles, and dorsal vessel can be distinguished before segmentation is completed. At about the same time movement by the larva appears to rupture the walls of the yolk cells surrounding the body, and forces the contents toward the anterior end of the body, where it is swallowed. After intermittent periods of activity and rest the larva is then ready to hatch.

Hatching

The larva, when ready to hatch, is in a U-shaped position and occupies almost the entire space within the egg. Contact with the eggshell is loosened by backward and forward movements of the body, and the larva retracts its head before forcing the mouth parts against the shell. The mandibles operate with a pincerlike action in tearing the hole through which it later escapes. As soon as the jaws break through, the head and first two segments are thrust out, and the larva employs its posterior legs and setae to good advantage in crawling free from the collapsed shell. From the time when the mandibles first penetrated the shell until the larva crawled away, hatching was observed to require from 4 to 46 minutes.

Observations on hatching from a cluster of eggs show that the larvae may begin emerging one after another but that sometimes two or three may emerge at the same time. In a group of five larvae which hatched March 25, two larvae becoming active at the same time showed a difference of only 20 seconds in time of hatching. The other three hatched at intervals of 15 and 30 minutes later. On April 14, hatching began in a group of seven eggs at 1.54 p. m. and was completed two hours later. The larvae within two eggs, which were partially overlapping, became active at the same time, but interfered to such an extent that one required two minutes longer than the other to get free from the shell. The observations in Table IV show the intervals of time required between the breaking of the shell and the crawling away of the freed larva.

TABLE IV.—*Time spent in the hatching process by larvae of Phlyctaenia rubigalis*

Date	Time of hatching	Minutes	Date	Time of hatching	Minutes
Mar. 18	8.59 a. m. to 9.03 a. m.	a 4	Apr. 14	11.19 a. m. to 11.24 a. m.	5
25	11.02 a. m. to 11.10 a. m.	8	14	12.49 p. m. to 12.53 p. m.	4
25	11.02 a. m. to 11.10 a. m.	8	14	12.54 p. m. to 12.59 p. m.	5
25	11.30 a. m. to 11.37 a. m.	7	14	1.54 p. m. to 1.58 p. m.	4
25	11.45 a. m. to 11.52 a. m.	7	14	2.52 p. m. to 3.01 p. m.	9
25	11.45 a. m. to 11.57 a. m.	12	14	2.59 p. m. to 3.03 p. m.	4
25	1.15 p. m. to 2.00 p. m.	45	14	3.00 p. m. to 3.06 p. m.	6
25	2.57 p. m. to 3.06 p. m.	9	14	3.15 p. m. to 3.20 p. m.	5
26	10.35 a. m. to 10.47 a. m.	12	14	3.36 p. m. to 3.40 p. m.	4
26	12.14 p. m. to 1.00 p. m.	46	14	3.52 p. m. to 3.56 p. m.	4
Apr. 13	9.48 a. m. to 9.50 a. m.	a 2	14	4.04 p. m. to 4.10 p. m.	6
13	10.36 a. m. to 11.08 a. m.	32	19	3.18 p. m. to 3.23 p. m.	5
14	10.14 a. m. to 10.19 a. m.	5	19	3.23 p. m. to 3.27 p. m.	4
14	10.46 a. m. to 10.51 a. m.	5	19	3.20 p. m. to 3.25 p. m.	5
14	10.56 a. m. to 11.04 a. m.	8	19	3.25 p. m. to 3.29 p. m.	4
14	11.17 a. m. to 11.21 a. m.	4	19	3.27 p. m. to 3.31 p. m.	4

a Head and two segments free before time was noted.

LARVAL STAGES

Development

Five larval stages were observed between the time of hatching and pupation. In each case the larvae molted after approximately equal feeding periods. They became inactive usually within a slight shelter of webbing or tied leaves, soon losing their greenish color, and appearing whitish or cream colored before casting their skins. Molting frequently occurred over night after which feeding was soon resumed. The most conspicuous part of the cast skin is the chitinized head covering, which is usually yellowish brown, becoming nearly colorless in the later stages, but in the case of the first molt it is black.

The newly hatched larva (Pl. 2, C) is about a millimeter long and very slender. Its shining translucent, creamy-white color changes to pale green as soon as feeding begins, owing to the food contents which are visible through the body wall. The black color of the head, which is conspicuous during the first larval stage, sometimes persists until the second molt, after which it becomes pale brownish with darker blotches on each side. The body soon acquires the characteristic dark green longitudinal stripes with lighter ones on either side. With successive molts these markings become more pronounced and the tubercles also become more prominent. There is very little change except in size during the later stages. The most striking increase in size appeared to occur during the first and in the final stages.

As illustrated in Table V, the first molt may occur from 2 to 5 days after hatching, and is usually followed by a second molt from 2 to 6 days later, at which time the black heads disappear and the larvae are approximately 2.5 mm. long. After feeding from 2 to 5 days the larva molts for the third

TABLE V.—*Observations on molting and duration of larval periods of Phlyctaenia rubigalis*

Date of hatching	Dates of molting					Duration of larval stages					Total larval period
	First	Second	Third	Fourth	Fifth	First	Second	Third	Fourth	Fifth	
1921						*Days*	*Days*	*Days*	*Days*	*Days*	*Days*
Jan. 28	Feb. 2	Feb. 5	Feb. 9	Feb. 14–15	Feb. 20	5	3	4	5–6	5–6	22–24
Jan. 29	Feb. 3	Feb. 7–9	Feb. 11	Feb. 16	do	5	4–6	2–4	5	4	22
Feb. 3	Feb. 5	Feb. 9	Feb. 14	Feb. 19	Feb. 21–25	2	4	5	5	2–6	18–22
Mar. 17	Mar. 20	Mar. 22–23	Mar. 25	Mar. 29	Apr. 4	3	2–3	2–3	4	6	18
Mar. 18			Mar. 28	Apr. 1	Apr. 6	3			4	5	19
Mar. 26	Mar. 29	Apr. 4				3	6				
Apr. 14	Apr. 17					3					
Apr. 19	Apr. 23					4					
Apr. 20	do					3					
Apr. 30	May 3	May 6	May 10–11			3	3	4–5			
May 3	May 7	May 12				4	5				
May 5	May 9					4					
Nov. 1	Nov. 5	Nov. 8–10				4	3–5				
Nov. 3	Nov. 7	Nov. 10		Nov. 19	Nov. 23	4	3			4	20
Nov. 15	Nov. 18	Nov. 21			Nov. 30	3	3				15

time. In the fourth stage, which lasts from 2 to 6 days, they are usually 7 to 9 mm. in length. The fifth stage also requires from 2 to 6 days and is concluded by the fifth molt just prior to pupation; the larvae in this stage are from 14 to 18 mm. long, but when full-grown they are about 18 mm. long (Pl. 2, D, E). Observations based on 171 larvae representing five generations indicate that it requires from 15 to 30 days, with an average of about 21 days (see Table VI), to complete the larval development.

TABLE VI.—*Duration of larval period of Phlyctaenia rubigalis*

Generation	Number of larvae	Duration of larval period	
		Minimum	Maximum
		Days	*Days*
Second	25	22	30
Third	82	17	28
Fourth	2	17	21
Eighth	36	18	23
Ninth	26	15	20

Larval coloration varies with the kind of plant on which the larva is feeding. On cinerarias the larvae are more yellowish-green than on marguerites, and on primulas they acquire a bright-green color; but the relation is most pronounced in the case of coleus which gives them a dull reddish-brown appearance.

Feeding Habits

The larvae upon hatching show more or less activity and move about on the surface of the foliage, apparently in search of an abrasion or place to begin feeding; they remain, however, grouped on the leaf upon which eggs were deposited and from which they hatched. They usually feed on the lower side of the leaf, or in the rolled leaf, or in leaves webbed together for their protection. When feeding their heads are bent at almost right angles to the body and small pieces of the leaf are gnawed out from circular holes which are enlarged as the larvae continue to feed along the edges. In the later feeding the small areas coalesce, resulting in the destruction of the entire leaf surface upon which they are feeding. There is a marked change in the size of the larvae between the time of hatching and a few hours after feeding. In some instances they become at least four times their original size. As newly hatched larvae they apparently have some difficulty in beginning a feeding area, and it has been noticed that they tug, tear, pull, or dig at the leaf surface in order to break through the tissues, but whenever an abrasion occurs it is quite promptly made their point of attack.

The exact type of injury varies somewhat in the case of different host plants. On cinerarias and marguerites they skeletonize the leaves, usually feeding on the lower surface, and on the latter they also draw the leaves together, while on the rose they appear to chew small pieces of the under surface of the leaves. They ate small round holes through violet leaves or else they fed on the under surface, leaving only the epidermis of the upper surface intact, giving it a blotched appearance. Even though the rose is reported as one of its favorite hosts in some sections, several attempts to rear larvae on it in the laboratory failed since they would invariably spin silken strands to lower themselves from the plant, and crawl away.

During periods of rest the transparency of the body tissues permitted observations on the complete process of digestion through the alimentary canal. The young larvae when disturbed suspend themselves from the leaf by spinning a silken strand on which they sway backward and forward, clinging to any object which they may encounter. They are able to cross gaps from one leaf surface to another by stretching or reaching across, resting on the prolegs during the operation. Feeding has been observed on the sides of the veins and tips of the leaves, and at times they may eat a narrow strip along the under side of the leaf and afterward draw it together with webbing.

Web Making

As a general rule web making or spinning does not take place until after the larvae begin feeding. In the case of a larva hatched four hours before, the following procedure was observed: The anterior portion of the body swayed backward and forward, evidently in search of a resting place for the legs while hanging on with the prolegs, the head and first anterior segment moving together, with only slight motion of the second and third segments. Since strands of silk were noticed emanating from the mouth, these actions were apparently associated with web making. The first pair of legs was used in attaching webbing to the tips of the leaf hairs. A single strand was first made, then several others were joined to it at a central point to form a web surface, similar to a spider web. As soon as a small area of the leaf surface had been covered with webbing to afford protection and support, the larva devoured a portion of the leaf tissue equal to the size of its head. It

then resumed spinning, later continuing to feed in the same hole and consuming about the same amount each time. After sufficient webbing had been formed, the larva crawled under it and fed at intervals, with intermittent periods of inactivity.

In another instance a larva, while hatching, constructed webbing with diagonal and cross strands, which it appeared to use as a foothold or brace in extricating itself from the eggshell, and as a path on which to crawl out.

Webbing is associated with feeding during the several stages, and especially at the time of molting. Just prior to pupation the full-grown larva spins a slight silken cocoon within which the pupa transforms to the moth.

PUPAL STAGE

Pupation takes place in folded leaves, except when the plant is so badly skeletonized that the larva crawls off to seek the shelter of some crevice or protected place. When the full-grown larva is ready to pupate, it forms a hiding place in one of the following ways, depending on the kind of leaves available: On geraniums it sometimes cuts each side of a portion of the leaf and folds it back, or it curls the edge of a leaf under, or laps a portion of the leaf surface which it fastened on the lower surface; and on marguerites and chrysanthemums it rolls over portions of the leaf so carefully that it is difficult to detect the presence of the pupa within.

The larva, which lines the leaf with a loose web of rather tough, white, silken strands, remains inside until it has transformed to the moth and is ready to emerge. It soon loses its characteristic greenish appearance, becoming distinctly cream colored or yellowish, and its body contracts, so that it is much shorter and thicker. This prepupal stage was observed to last less than a day. The pupal case, within which transformation takes place, is soon formed, being light colored at first but usually growing darker in a few hours. With the exception of occasional lighter and darker specimens the majority of the pupae have a shining chocolate-brown color (Pl. 2, F).

Observations on 142 individuals, as shown in Table VII, representing six generations, indicate that it requires from 6 to 16 days, with an average of about 10 days, for the pupal period.

TABLE VII.—*Duration of pupal stage of Phlyctaenia rubigalis*

Generation	Number of pupae	Duration of pupal stage	
		Minimum	Maximum
		Days	*Days*
First	7	10	12
Second	30	11	16
Third	54	7	15
Fourth	2	9	
Eighth	23	6	10
Ninth	26	8	10

SEASONAL HISTORY

TABLE VIII.—*Length and sequence of life cycles of Phlyctaenia rubigalis, 1921*

Generation	Number of specimens	Dates of—		Length of life cycle
		Egg deposition	Adult emergence	
				Days
First	7		Jan. 17 to 20	(a)
Second	5	Jan. 23	Mar. 4 to 6	40–43
	8	Jan. 23	Mar. 7 to 8	43–44
	2	Jan. 25	Mar. 8 to 9	42–43
	7	Jan. 25	Mar. 9 to 14	43–48
	1	Jan. 23	Mar. 24	60
Third	8	Mar. 8	Apr. 15 to 16	38–39
	12	Mar. 9	Apr. 17 to 20	39–42
	31	Mar. 9	Apr. 21 to 24	43–46
	10	Mar. 9	Apr. 25 to 29	47–51
	12	Mar. 10	Apr. 15 to 16	36–37
Fourth	(b)	Apr. 18 to May 2	May 26 to June 16	38
Fifth	(b)	May 27	July 1 to 15	35
Sixth	(b)	July 2	Aug. 10	39
Seventh	11	Aug. 10	Sept. 14 to 17	35–38
	21	Aug. 12	Sept. 18	37
	41	Aug. 13	Sept. 19 to 23	37–41
	5	Aug. 17	Sept. 24	38
Eighth	2	Sept. 19	Oct. 24 to 26	35–37
	6	Sept. 22	Oct. 31 to Nov. 4	39–43
	5	Sept. 23 to 24	Nov. 7 to 8	45
	2	Sept. 26	Nov. 8 to 9	43–44
	5	Sept. 27 to 29	Nov. 9 to 10	42–43
	3	Sept. 30	Nov. 8	39
Ninth	4	Oct. 29	Dec. 2	34
	5	Nov. 1	Dec. 2	31
	12	Nov. 9	Dec. 8 to 9	29–30
	5	Nov. 10	Dec. 10 to 12	30–22

[a] Partial life cycle. [b] Specimens not confined.

As may be observed in Table VIII nine distinct generations were reared during 1921, indicating that there may be a definite overlapping of generations throughout the year under greenhouse conditions. The first seven moths, which began emerging January 17 from nearly full-grown larvae received January 5, were considered as completing a partial first generation. Twenty-three adults of the second generation began appearing March 4. The life cycle of 73 moths was observed during the third generation and the first individuals emerged on April 15. Observations on the fourth, fifth, and sixth generations were made on specimens reared under normal greenhouse conditions because the high temperatures prevailing during June, July, and August made it difficult to rear them in cages. The first adults of the seventh, eighth, and ninth broods appeared on the following dates: September 14, October 24, and December 2, with totals of 78, 23, and 26 specimens, respectively. The time between emergence of the first adults of the ninth generation and January 5 of the ensuing year would allow sufficient time for the completion of the partial first generation mentioned above. Like other insect pests which live both indoors and outdoors, the greenhouse leaf-tyer apparently flourishes best under glass during the winter and spring months, at which time its depredations are most frequently reported. In the summer months it causes serious injury outdoors on truck and garden crops, especially on celery, beets, and lettuce.

NATURAL ENEMIES

In the course of these life-history studies, spiders and ants proved to be important enemies of *Phlyctaenia rubigalis*. Small spiders of the species *Theridium tepidariorum* Koch, which conceal themselves along the sides of the flowerpots, or even on the leaves of infested plants, confined their attention to destroying the larvae and adults, while the pupae were apparently unmolested. The spider first renders its victim helpless by entangling it with a few strands of webbing and then puncturing it and later sucking the entire body contents.

The small red ant sometimes called Pharaoh's ant, *Monomorium pharaonis* L., was not observed to disturb the eggs but attacked all other stages, being especially destructive to the pupae and moths. These ants chewed the pupae into bits and devoured them, and not only ate the bodies of the moths, but even carried away pieces of the wings.

No insect parasites were reared from any of the material used in these experiments, but the following natural enemies have been recorded as occurring in the United States:

Chittenden (*3, p. 19*) says: "A single parasite of this species has been observed, the only natural enemy that appears to be known for it. Among a lot of larvae from Livonia, Pa., a cocoon was found May 19, which gave the imago May 27. It was identified by Mr. Ashmead as a species of Synetaeris, an ichneumonid genus related to Limneria."

J. J. Davis (*4, p. 100*) reports: "A hymenopterous parasite of this leaf-tier was common in the greenhouses of Chicago, and no doubt in many of them it was doing much to hold the leaf-tier in check. The species was determined by Chas. T. Brues as *Apanteles glomeratus* Linn. A tachinid fly bred from this leaf-tier was determined by C. A. Hart as *Phorocera parva* Bigot."

According to Gibson (*6, p. 629*) no parasites were reared from Canadian material.

CONTROL

Since a review of published records and recent correspondence relating to this pest indicates that none of the recommendations for control have proved entirely satisfactory, experimental work was conducted that further data on this subject might be obtained. These tests included fumigation with hydrocyanic-acid gas and dipping, spraying, or dusting with insecticides.

FUMIGATION WITH HYDROCYANIC-ACID GAS

Although some writers have suggested the use of hydrocyanic-acid gas, its use has generally been discouraged because burning of the tender growth frequently has accompanied such treatment when employed at sufficient concentration to kill the moths. Recent experience, however (*12*), indicates that although slight temporary injury may occur on such plants as jasmine, ageratum, German ivy, chrysanthemum, marguerite, salvia, geranium, dahlia, cestrum, heliotrope, and stephanandra, no permanent injury will result. In the case of violets, Chittenden (*3, p. 20*) recommends it as a most satisfactory remedy, but he also says that "it can not yet be safely used for the fumiga-

tion of certain other plants owing to the danger of bleaching and otherwise injuring them." In a footnote he states that Slingerland (*13, p. 163–164*) "tested this gas against this leaf-tyer, and his experiments show that the gas does not kill moths, pupae, and grown larvae when used at the ordinary strength, but only small larvae."

Britton (*2, p. 370*) recommends fumigation with this gas at the rate of 0.1 to 0.15 grams of 98 per cent potassium cyanide for each cubic foot of space (or 3.5 ounces per 1,000 cubic feet). Expressing this dosage in terms of sodium cyanide (which is now generally used for fumigation purposes), it would be equivalent to 2.64 ounces of sodium cyanide, an amount greatly in excess of dosages which can be safely employed for general greenhouse fumigation.

Moreover, results of recent experiments indicate that the egg, larval, and pupal stages are not affected by fumigation with dosages ranging from one-fourth to one-half ounce sodium cyanide per 1,000 cubic feet of space that are ordinarily employed.

To throw more light on this point the experiments recorded in Table IX were undertaken with plants harboring all stages of the leaf-tyer.

From the results obtained it is quite clear that the moths ultimately succumb to the above dosage of the gas, and may be effectively controlled provided the plants concerned can tolerate it. Furthermore, no egg deposition took place from the time of exposure to the gas until the death of the moths. The larvae and pupae developed normally and were not affected by this treatment. Moreover, pupae placed in a cyanide bottle from one-half hour to 24 hours emerged later as normal moths. All controls developed normally.

Incidentally, fumigation with tobacco has proved ineffective against any and all stages of the insect.

TABLE IX.—*Fumigation with hydrocyanic-acid gas for the control of all stages of Phlyctaenia rubigalis* [a]

Experiment No.	Date	Number of specimens	Observations and results
	1921		
I	Apr. 6	36 moths	Apr. 7, 12 moths dead, 24 alive. Apr. 8, 21 moths dead, 3 alive. Apr. 9, all moths dead.
		10 larvae	No effect, all developed normally.
		5 pupae	No effect, all emerged normally.
		15 eggs [b]	No effect, all hatched normally.
Control	Apr. 6	4 moths	Normal, egg depostion continued.
		60 larvae	Normal, developed to pupae.
		15 pupae	Normal, developed to adults.
		59 eggs	Hatched normally.
II	Apr. 25	15 moths	Apr. 25, at close of fumigation all moths were lying at bottom of cage. Apr. 26, 9 a. m., 14 moths alive, 1 dead. Apr. 26, 3.45 p. m., 5 moths alive, 9 dead. Apr. 28, 9 a. m., all dead.
		100 eggs	No effect, all hatched.
Control	Apr. 25	144 moths	Normal development.
		800 eggs	Normal hatching.

[a] In each of these experiments 1 ounce of sodium cyanide per 1,000 cubic feet of space was used with an exposure to the gas lasting 1 hour, and at temperatures of 73° F. and 76°, respectively.

[b] These eggs were deposited by the moths just prior to fumigation.

TABLE X.—*Results of tests to determine residual insecticidal action as well as the immediate effect of contact insecticides on eggs of Phlyctaenia rubigalis*

Experiment No.	Date sprayed	Dosage and treatment	When treated	Number of eggs	Date of—		Observations and results
					Deposition	Hatching	
	1921						
I	Apr. 25	40 per cent nicotine sulphate, 1-800; no soap; entire plant dipped.	Before deposition.	190	Apr. 26	May 3	May 3, no effect on hatching; lower leaves died, possibly owing to dipping; larvae fed heavily, and 9 days later plant was ruined.
II	do	Same as in Experiment I.	After deposition.	55	Apr. 24	Apr. 30	Apr. 30, eggs hatched.
					Apr. 29		May 12, all larvae developing normally.
III	do	Soap solution, 1 ounce to 1 gallon water; 2 plants dipped.	Before deposition.	19	Apr. 26	May 4	May 4, no effect on hatching; lower leaves died; larvae fed heavily.
				24	do	May 5	May 12, plant ruined as result of feeding.
IV	do	Same as in Experiment III.	After deposition.	110	Apr. 25	May 3	May 3, eggs hatched; no effect on eggs or larvae. May 9, larvae fed so heavily that leaves were badly spotted.
V	do	40 per cent nicotine sulphate, 1-800; soap, 1 ounce to 1 gallon; plants dipped. For egg deposition at intervals of 1, 3, and 5 days, respectively.	Before deposition.	38	Apr. 26	May 4	May 4-10, no effect on hatching; larvae fed and developed normally. Eggs deposited Apr. 28-30 showed tendency to scale loose, but later hatched.
				45	Apr. 28	May 7	
				40	Apr. 30	May 10	
VI	do	Same as in Experiment V.	After deposition.	44	Apr. 25	May 3	May 3-10, eggs hatched; lower leaves showed slight injury; larvae developing normally.
					May 1-2	May 10	
VII	do	Control; no treatment.	Before deposition.	139	Apr. 29	May 8	May 8, all hatched and developed normally.
VIII	do	Control; no treatment.	After deposition.	90	Apr. 24	Apr. 30	May 8, all hatched and developed normally.

TESTS FOR THE DESTRUCTION OF EGGS BY DIPPING PLANTS IN CONTACT INSECTICIDES BEFORE AND AFTER EGG DEPOSITION

In some previous experimental work (*11, p. 17–18*) with insecticides, it was observed that a residual or continued insecticidal action often operates against eggs subsequently deposited on foliage which has been treated. Accordingly plants were dipped both before and after deposition of eggs, contact poisons being used as indicated in Table X. In this way data were obtained on the residual insecticidal action as well as the direct effect of contact insecticides on the eggs.

These tests proved negative so far as throwing any light on the residual or immediate contact effect of insecticides on eggs of the greenhouse leaf-tyer.

TESTS FOR THE DESTRUCTION OF EGGS BY SPRAYING PLANTS WITH ARSENICALS BEFORE AND AFTER EGG DEPOSITION

Further tests were then made, arsenicals being substituted for the contact sprays, as indicated in Table XI, it being assumed that the young larvae would naturally feed on the poisoned foliage after hatching.

Arsenicals, either alone or combined with nicotine sulphate, proved only partially effective against the eggs, but as soon as the larvae hatched and fed on the arsenical-coated foliage, they died. Although burning was evident in one case, subsequent experiments showed that the plants tolerate this treatment. The whitish deposit which remains on foliage so treated may be objectionable from a commercial point of view, but when applied to young plants this deposit is left behind as growth continues.

TABLE XI.—*Results of tests to determine effect, on eggs of Phlyctaenia rubigalis, of spraying plants with arsenicals before and after egg deposition*

Experiment No.	Date sprayed	Dosage and treatment	When sprayed	Number of eggs	Date of—		Observations and results
					Deposition	Hatching	
I	1921 Apr. 25	Lead arsenate, 1 ounce to 1 gallon water.	Before deposition.	46	Apr. 26	May 3	May 3, no effect on egg stage; all larvae dead or missing 4 days later; severe burning on tips of plants.
II	do	Same as Experiment I.	After deposition.	46	Apr. 24	Apr. 30	May 2, 8 eggs failed to hatch; larvae feeding, but disappeared May 3.
				49	Apr. 29	May 9	May 3, all disappeared.
III	do	do	Before deposition.	49	do	May 7	May 7, some eggs failed to hatch; no live larvae on plant 5 days later.
IV	do	Same as Experiment I, plant sprayed just before eggs hatched.	After deposition.	89	Apr. 17	Apr. 25	May 26, a few larvae dead; some alive, but suspended from leaves. May 27, 8 larvae dead. May 29, all larvae dead.
V	do	Lead arsenate, 1 ounce to 1 gallon water; 40 per cent nicotine sulphate, 1–800.	Before deposition.	73	Apr. 26	May 4	May 3, some eggs scaled loose from leaf; a few dried and failed to hatch. May 9, no larvae remained; no injury to plant.
VI	do	Same as Experiment V.	After deposition.	28	Apr. 24	May 2	May 2, eggs hatched.
				78	May 1–2	May 9–10	May 9, all larvae dead.
VII		Control; no treatment.		90	Apr. 27	May 4	May 4, eggs hatched and larvae developed normally.
VIII		do		44	Apr. 25	May 3	May 3, all larvae developed normally.

TABLE XII.—*Control of larvae of Phlyctaenia rubigalis by spraying with or dipping in arsenate of lead*

Experiment No.	Treatment, Apr. 8, 1921	Total number of larvae	Number of dead larvae	Date of death	Observations and results
				1921	
I	Plant sprayed with lead arsenate, 1 ounce, powdered, to 1 gallon water.	28	21	Apr. 9	Apr. 16, 24 dead, 4 disappeared.
			2	Apr. 11	
			1	Apr. 12	
II	Plant dipped in lead arsenate, 1 ounce, powdered, to 1 gallon water.	33	22	Apr. 9	Apr. 20, 27 dead, 6 disappeared.
			3	Apr. 11	
			1	Apr. 18	
			1	Apr. 20	
III	Plant dipped in lead arsenate, 1 ounce, powdered, to 1 gallon water, plus 40 per cent nicotine sulphate, 1–800.	20	12	Apr. 9	Apr. 20, 16 dead, 4 disappeared.
			3	Apr. 11	
			1	Apr. 20	
IV	Control; no treatment	12	0		Larvae developed normally; pupated April 16.

SPRAYING AND DIPPING TESTS FOR THE CONTROL OF LARVAE WITH ARSENATE OF LEAD

Further tests were then conducted to determine the effectiveness of spraying plants with arsenate of lead, or dipping them in this arsenical, for the control of partially grown larvae. The results of these experiments are given in Table XII.

DUSTING TESTS FOR THE CONTROL OF LARVAE

The results obtained by dusting with the arsenical-sulphur mixtures, as shown in Table XIII, were gratifying and hardly need further comment, except the statement that in the earlier tests a few individuals crawled away from the treated plants and were lost, because the plants were not confined within cages. Without exception, however, when such specimens were located they were dead, and were easily identified by the characteristic arsenical poisoning displayed by them when succumbing to this insecticide. The larvae, after feeding on the dusted foliage, soon lose their normal greenish color, becoming sluggish and limp. After death their bodies are rather soft and have a sickly yellowish color.

Results of these tests show a definite control, indicating that timely spraying with or dipping in arsenate of lead is effective in killing the larvae.

DUSTING TESTS FOR THE CONTROL OF THE MOTHS

During the spring of 1924, in preliminary experiments, nicotine dusts containing 5 per cent of nicotine sulphate (2 per cent pure nicotine) proved effective in killing the moths. In these tests the specimens were confined in wire cages and the dust was applied with a small hand duster. The dusts were prepared by impregnating hydrated lime with a 40 per cent nicotine sulphate solution according to formula No. 2, on page 5 of Farmers' Bulletin 1282.

TABLE XIII.—*Control of larvae of Phlyctaenia rubigalis by dusting*

Experiment	Date	Plant	Treatment	Total number of larvae	Number of dead larvae	Date of death	Observations and results
I	1921 Apr. 8	Cineraria	Lead arsenate, 10 per cent; sulphur, 90 per cent.	58	26	Apr. 9	42 dead larvae; 6 alive; 10 disappeared; 72 per cent kill.
					13	Apr. 11	
					1	Apr. 12	
					2	Apr. 16	
II	Apr. 8	Marguerite	Same as Experiment I.	13	1	Apr. 9	1 larva dead; 11 disappeared; 1 pupated.
III	May 13	Calendula	do	23	17	May 14	17 dead; 5 disappeared; 1 alive; 74 per cent kill.
						May 17	
IV	May 16	do	do	19	3	May 17	May 23: 100 per cent kill.
					8	May 18	
					6	May 19	
					2	May 23	
V	May 16	do	Calcium arsenate, 10 per cent; sulphur, 90 per cent.	41	6	May 17	40 larvae dead within 1 week; 1 pupated (plants treated 3 days before larvae were due to pupate); 97 per cent kill.
					16	May 18	
					5	May 19	
					5	May 20	
					7	May 23	
					1	May 24	
VI	May 12	Marguerite	Lead arsenate, 15 per cent; sulphur, 85 per cent.	36	32	May 13	100 per cent kill; larvae 1 week old; all dead within 40 hours after dusting.
					4	May 14	
VII	May 12	do	Same as Experiment VI.	23	20	May 13	100 per cent kill.
					3	May 14	
VIII	May 13	Calendula	Lead arsenate, 20 per cent; sulphur, 80 per cent.	25	20	May 14	May 14, 20 larvae 1 week old killed; 4 alive but later disappeared; 80 per cent kill.
IX	May 16	do	Same as Experiment VIII.	13	6	May 17	100 per cent kill.
					1	May 18	
					5	May 19	
					1	May 20	
X	May 12	do	Lead arsenate, 10 per cent; tobacco dust, 10 per cent; sulphur, 80 per cent.	35	26	May 13	35 larvae 2 weeks old killed; 100 per cent kill.
					3	May 14	
					3	May 16	
					3	May 17	

Even though there has been no opportunity to test this treatment on a commercial scale, the indications are so promising that it seems desirable to include the use of nicotine dust in the control program. The plants are not injured, and the moths and some of the younger larvae hit by the dust are killed. Moreover, because of the ease of application many florists will no doubt prefer to use the dust rather than fumigate with hydrocyanic-acid gas.

SUMMARY AND CONCLUSIONS

The preceding data bring out certain features which may be used as a basis upon which to formulate a definite control program. Briefly summarized, the life-history studies show that this insect breeds practically without interruption, and that all stages are likely to be found in greenhouses throughout most of the year. The destruction of plants is due to the feeding of the larvae, which later increase the injury by tying themselves up in the foliage prior to pupation, thus causing further disfigurement and consequent decrease in commercial value. The pupae are well protected by the formation of the pupal case within tied leaves lined with a rather tough silken cocoon. The adults are nocturnal in habit.

The results of the control experiments indicate (1) that the adults may be successfully controlled by fumigation with hydrocyanic-acid gas, or by dusting with a 5 per cent nicotine sulphate dust; (2) that the eggs are impervious to contact insecticides; (3) that the larvae succumb to the effects of arsenical poisons when applied either in the dry or liquid form, and (4) that the pupae are virtually immune from all artificial control measures, except hand picking, because of their protection and resistance. It is evident, therefore, that an effective control program necessitates simultaneous direction of efforts against the susceptible stages, which are the adults and larvae.

RECOMMENDATIONS

In case of a heavy existing infestation the following drastic control measures are recommended: Fumigate after dusk twice at intervals of seven days with hydrocyanic-acid gas, using 1 ounce of sodium cyanide per 1,000 cubic feet of air space, with an exposure lasting for one hour. The first fumigation will operate against all moths which are present at the time of fumigation, and the second will kill all moths which have emerged since. The day following the first fumigation the plants should be treated with the arsenical insecticides as outlined in the paragraphs below.

When it is not feasible to fumigate with hydrocyanic-acid gas, persistent dusting with a 5 per cent nicotine sulphate dust is recommended.

For plants which are well developed and of large size, or growing in permanent beds, dusting with a dry mixture consisting of 1 part of calcium arsenate or arsenate of lead and 9 parts of superfine sulphur is very effective, and should be applied by means of a modern type of hand duster or blower gun. This treatment has the advantage of sifting the insecticide through the webbing which the larvae spin, as well as poisoning the leaf surface on which they feed. It possesses the additional advantage of overcoming the unsightly deposit which follows the application of liquid arsenical sprays.

For low-growing or potted plants, spraying with lead arsenate or calcium arsenate solution, prepared by dissolving 1 ounce of the powdered form in each gallon of water used, is recommended. Spray solutions are desirable for the treatment of the smaller plants because the entire plant may be dipped directly in the solution or else sprayed with a knapsack or compressed-air sprayer, an angled nozzle being used so that the spray can be directed to all surfaces of the infested foliage.

The most important considerations in controlling the larvae or caterpillars are promptness and thoroughness in the applications of the poison, especially to the under side of the leaves where the larvae feed. Since the young larvae are less resistant to the insecticides soon after hatching and before they become webbed-in on the leaves, they can be more easily destroyed at this stage and, moreover, there is less risk of the plants becoming seriously disfigured. After the webbing is formed it is difficult to coat the foliage with a liquid spray because the silken fibers prevent the insecticide from reaching the leaf. It is also imperative that the plants be kept constantly covered with the spray.

In case of a light infestation, or one which is discovered in its incipiency, going over the plants daily and picking and destroying any that may be found will prove effective.

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